SHC
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Advances in Housing Retrofit

Processes, Concepts and Technologies

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Task 37 – Advanced Housing Renovation with Solar and Conservation

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IMPRESSUM

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IEA Solar Heating and Cooling Programme

The International Energy Agency (IEA) is an autonomous body within the framework of the Organization for Economic Co-operation and Development (OECD) based in Paris. Established in 1974 after the first "oil shock," the IEA is committed to carrying out a comprehensive program of energy cooperation among its members and the Commission of the European Communities.

The IEA provides a legal framework, through IEA Implementing Agreements such as the Solar Heating and Cooling Agreement, for international collaboration in energy technology research and development (R&D) and deployment. This IEA experience has proved that such collaboration contributes significantly to faster technological progress, while reducing costs; to eliminating technological risks and duplication of efforts; and to creating numerous other benefits, such as swifter expansion of the knowledge base and easier harmonization of standards.

The Solar Heating and Cooling Programme was one of the first IEA Implementing Agreements to be established. Since 1977, its members have been collaborating to advance active solar and passive solar and their application in buildings and other areas, such as agriculture and industry. Current members are:

Australia
Austria
Belgium
Canada
Denmark
European Commission
Germany
Finland
France
Italy
Mexico
Netherlands
Norway
Portugal
Singapore
South Africa
Spain
Sweden
Switzerland
United States

A total of 49 Tasks have been initiated, 34 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition to the Task work, a number of special activities — Memorandum of Understanding with solar thermal trade organizations, statistics collection and analysis, conferences and workshops — have been undertaken.

Visit the Solar Heating and Cooling Programme website - www.iea-shc.org - to find more publications and to learn about the SHC Programme.

Current Tasks & Working Group:

Task 36	Solar Resource Knowledge Management
Task 38	Solar Thermal Cooling and Air Conditioning
Task 39	Polymeric Materials for Solar Thermal Applications
Task 40	Towards Net Zero Energy Solar Buildings
Task 41	Solar Energy and Architecture
Task 42	Compact Thermal Energy Storage
Task 43	Solar Rating and Certification Procedures
Task 44	Solar and Heat Pump Systems
Task 45	Large Systems: Solar Heating/Cooling Systems, Seasonal Storages, Heat Pumps
Task 46	Solar Resource Assessment and Forecasting
Task 47	Renovation of Non-Residential Buildings Towards Sustainable Standards
Task 48	Solar Cooling - Quality Assurance Measures for Solar Thermally Driven Heating and Cooling Systems
Task 49	Solar Heat Integration in Industrial Processes

Completed Tasks:

Task 1	Investigation of the Performance of Solar Heating and Cooling Systems
Task 2	Coordination of Solar Heating and Cooling R&D
Task 3	Performance Testing of Solar Collectors
Task 4	Development of an Insolation Handbook and Instrument Package
Task 5	Use of Existing Meteorological Information for Solar Energy Application
Task 6	Performance of Solar Systems Using Evacuated Collectors
Task 7	Central Solar Heating Plants with Seasonal Storage
Task 8	Passive and Hybrid Solar Low Energy Buildings
Task 9	Solar Radiation and Pyranometry Studies
Task 10	Solar Materials R&D
Task 11	Passive and Hybrid Solar Commercial Buildings
Task 12	Building Energy Analysis and Design Tools for Solar Applications
Task 13	Advanced Solar Low Energy Buildings
Task 14	Advanced Active Solar Energy Systems
Task 16	Photovoltaics in Buildings
Task 17	Measuring and Modeling Spectral Radiation
Task 18	Advanced Glazing and Associated Materials for Solar and Building Applications
Task 19	Solar Air Systems
Task 20	Solar Energy in Building Renovation
Task 21	Daylight in Buildings
Task 22	Building Energy Analysis Tools
Task 23	Optimization of Solar Energy Use in Large Buildings
Task 24	Solar Procurement
Task 25	Solar Assisted Air Conditioning of Buildings
Task 26	Solar Combisystems
Task 27	Performance of Solar Facade Components
Task 28	Solar Sustainable Housing
Task 29	Solar Crop Drying
Task 31	Daylighting Buildings in the 21st Century
Task 32	Advanced Storage Concepts for Solar and Low Energy Buildings
Task 33	Solar Heat for Industrial Processes
Task 34	Testing and Validation of Building Energy Simulation Tools
Task 35	PV/Thermal Solar Systems
Task 37	Advanced Housing Renovation with Solar & Conservation

Completed Working Groups:

CSHPSS; ISOLDE; Materials in Solar Thermal Collectors; Evaluation of Task 13 Houses; Daylight Research

Content

1 Introduction

Sebastian Herkel

Retrofit of existing housing stock is a mayor challenge in the international activities to face climate change. In mature economies in the northern hemisphere up to 30 % of the primary energy is used in the housing sector. Thus research related to retrofit of the existing building stock is one of the key topics in the Strategic plan of the IEA Solar Heating & Cooling Program.

With 60 documented retrofitted buildings shows the different strategies and technologies available for advanced house retrofitting in the different participating countries. A detailed analysis shows that the Step towards Net Zero Energy Buildings is coming more to reality – even in housing retrofit.

This source book deals with processes, concepts, economy and technologies which are all relevant to achieve the approach of a significant reduction of the energy demand in combination with an efficient energy supply based on renewable sources.

The intention of this book is to give an insight in advances achieved within Task 37. It addresses professionals in the building sector as well as the scientific community. It's organized in a way that each chapter stands for itself addressing the different thematic areas.

In Chapter 2, *Processes* a design methodology is presented, energy ambition indicators of building concepts are introduced and examples for restructuring of floor plans and the underlying decisions were discussed. User's participation as a success factor for advanced housing renovation as well as the economics of high performance old house renovation projects is documented.

In Chapter 3, *Building Envelope* the typology, problems and solutions for the most important measure in advanced retrofit – the insulation – are described. A special focus is drawn on Interior Insulation and new technologies applying materials and systems like aerogel and vacuum insulation. The examples show general solutions without having the approach of a full scale thermal bridge catalogue.

In Chapter 4, *Ventilation* concepts on ventilation are described. Exhaust ventilation and free ventilation versus systems with heat recovery and concepts for hybrid ventilation are discussed. Results from a comparison of exhaust ventilation and balanced ventilation with heat recovery in a passive house retrofit based on measurements were evaluated in Germany.

In Chapter 5, *Supply systems* energy supply systems dealing with the net zero energy approach in refurbishment projects in Germany are evaluated by monitoring and further developed in simulation studies. Mechanical systems integrating "standard" system supplying air, heating and DHW developed in Canada are presented as well as integrated concepts dealing in addition with lowering the electricity needed for household appliances as done in the Netherlands.

In Chapter 6, *Implementation of Solar Thermal Systems in Renovation*" the integration for solar thermal supply solutions is discussed from a regional scale down to the component level. Various examples documents the advanced technology available and the need to address not only the component and building level when heading for an energy system based in renewables.

In Chapter 7, *Advanced Design Solutions* full scale retrofit concepts from Denmark are documented and examples for retrofit of buildings from the 1960's in Switzerland are documented.

In Chapter 8, *Performance* the results of a detailed analysis from exemplary Housing Renovations in Germany based on a detailed monitoring is given. A summary of 60 retrofitted building documented within Task 37 show the variety of solutions available for advanced housing retrofit for different building typologies, the technologies applied and show the performance achieved.

2 Processes

2.1 PIAF® design methodology

Ivo Opstelten

2.1.1 Introduction

Being aware that all buildings undergo several mutations during their lifespan, the future-oriented building has been introduced several years ago. This phrase can be interpreted in many ways:

- A building technology which allows for easy enlargement of the building as a whole.
- A building technology which allows for easy alteration of the layout of buildings (to allow e.g. for adaptation to changes in composition of the family)
- A building methodology aimed at the equipment of the building to facilitate living at home longer for the elderly (e.g. by a bath room on every floor and a wide stair case for a chair-lift and domotics)
- A building technology which leads to a low environmental burden (in general)

These phrases proved popular but are insufficient to base decisions upon to create the optimal building concept for any given situation. They provide more a line of reasoning than a design methodology leading to specific building concepts.

Following the 'no-regret' approach in development of new technologies and concepts a new dimension has emerged and been translated in a concrete design methodology: the PIAF® design methodology. The PIAF® design methodology, also sometimes referred to as the no-regret design methodology, is the acronym for **P**repared **I**n all **A**spects for **F**uture developments. The developments that are considered in this methodology are:

1. Developments with implications on security of supply of energy
2. Price developments of energy
3. Technological developments (either resulting in new technologies and/or improved existing technologies) and cost developments
4. Value driving aspects

Ad 1: The first aspect implies taking into account the level of autonomy which is desired by the consumer and/or the length of time that the consumer is willing to stay dependent on fuel resources which may become scarce at a certain point in time.

Ad 2: Taking into account possible energy price scenarios, as input for design choices, helps identify the range of impact of different building and energy systems on the integral living expenses.

Ad 3: Although popular believe has it that the build environment is not in need of any new technological innovations, a lot of several technological developments that are en route can be of interest, especially considering the next natural mutation moment of the building: replacement of HVAC systems.

Ad 4: Retrofitting a house for energy purposes alone, often limit the level of energy ambition realized, because in those cases payback times are a limiting factor. When, on the other hand the retrofit is seen as an opportunity to improve the property value, energy measures can piggy-back on those improvements and payback times no longer have to be the limiting factor. The enlargement of a building, combined with an improved level of insulation (up to passive house standard level), is such an example.

2.1.2 The four step approach

To design a building concept using the PIAF® methodology involves 4 steps:

1. Set an energy target for the building, to be reached at the next natural mutation moment: replacement of the HVAC system.
2. Determine the optimal HVAC system to put in place at that moment in time, composed from the best available technology (in terms of cost-performance ratio, taking into account the effect of energy price developments).
3. Determine the optimal building skin (in terms of cost-performance ratio, taking into account the effect of energy price developments) associated with the HVAC system resulting from 2.
4. Determine the optimal HVAC system (in terms of cost-performance ratio, taking into account the effect of energy price developments and impact of necessary alterations to the system of step 2 in the future) for the time until the next natural mutation moment.

It is clear that this methodology depends on several important factors:

- Accuracy of prediction of energy price developments
- Knowledge of energy aspects of new technological developments
- Knowledge of cost-development related to technological developments

2.1.3 Example

To illustrate the influence of energy price developments three energy price development scenarios have been examined for their influence on the accumulated costs of a house. The accumulated costs (vertical axes) are a summation of the investment (and financial) costs, the maintenance and the operational costs. The house considered is equipped with a gas-based heating system throughout the lifetime of the building skin (45 years) and the heating demand, determined by the building skin, is used as a variable (horizontal axes), see Figure 2.1-1 and Figure 2.1-2

It is most interesting to note, that the minimum in accumulated costs shift to the lower heating demands for higher energy price increases.

The PIAF® methodology has been used for the determination of the optimal set of building and system technologies to make house energy neutral by investments at the moment of renovation and system replacement 15 years after the renovation.

The accumulated costs of the system have been calculated and are compared for 4 different options:

1. no energy measures at all,
2. minor energy measures (replacement of the condensing boiler by a micro-CHP after 15 years),
3. creating an energy neutral building from the start,
4. The PIAF® building, consisting of high levels of insulation (Passive house standards), HR++ windows with shutters, a condensing boiler, replaced after 15 years by a seasonal heat storage system, fed by 8 m2 vacuum tube collectors and a full roof PV system.

The result is shown below. It can be seen that when the building is not seen as a static energy system the optimal heating demand changes from the Passive House standard, 15 kWh/m²/year, to a value between 25 and 35 kWh/m². The figure clearly shows the advantages of looking at energy measures, but most of all, of looking at them with an eye on future developments: PIAF®!

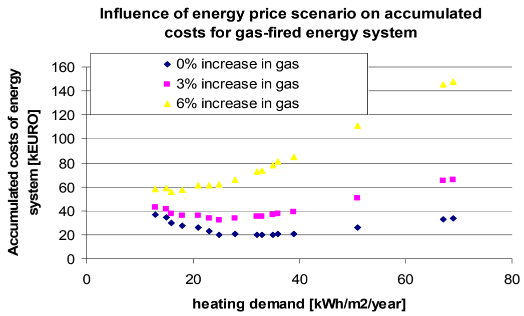


Figure 2.1-1
Influence of energy price scenario on accumulated costs for gas-fired energy system

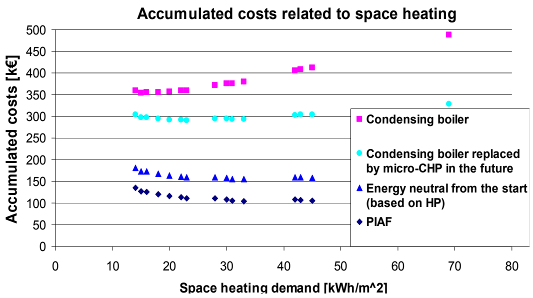


Figure 2.1-2
Accumulated costs related to space heating

2.2 Energy Ambition Indicator of Building Concepts

Ivo Opstelten

2.2.1 Introduction

In IEA Task 37, building concepts are conceived for renovation of existing buildings, which will considerably reduce the net energy usage, with respect to the energy usage before the renovation.

The emphasis on specific types of (set of) measures in the different renovation concepts can differ considerably, e.g. reduction of energy demand for heating/cooling and/or implementation of sustainable energy systems such as solar collectors and PV. Some might even include modification of the infrastructure in the building to fit in household appliances, which could contribute to further reduction of the total energy usage (e.g. hot fill, smart meters, etc.).

The targeted ambition for energy reduction of the Task 37 concepts has been set at a factor 4, so that a collection of really outstanding renovation concepts can be used as example of the current possibilities. The use of a factor as an indicator does however have the disadvantage that it is set against a certain reference. Without explicit communication what the reference for the factor is, different actors (dependent on their background and nationality) will implicitly use different references. This might ultimately lead to a collection that lacks a common ambition level, or is misinterpreted, which will stand in the way of successful dissemination.

On the other hand, in several countries, energy ambition indicators are already in use. Using a new indicator might in these cases just as well lead to confusion. In task 37, it was therefore decided to use a common indicator for all projects and a translation to national indicators for those cases where it is appropriate.

2.2.2 Considerations

Approximately 35% of all energy used in the EU is used in the built environment. This energy usage covers both building related energy (often from fossil fuels e.g. for room heating and domestic hot water) and user related energy (mainly electricity e.g. for domestic appliances). The relative magnitude of these two depends on the building sector (residential or non-residential) and type (high-rise, low-rise, detached). This implies that the optimal set of measures for energy reduction, probably also (at least partly) depends on the building sector and type.

The importance of energy efficiency and use of renewables stems from different elements:

- Security of supply and its impact on economics
- Environmental impact from use of energy

For a sound choice of a common energy ambition indicator, the underlying motivation for the factor 4 packages is also of importance. If the driving motivation stems from the aspect of security of supply and economics, communication in terms of energy is the most logical choice. If, however, the environmental impact is most important, communication in terms of CO2 and/or other environmental indicators is more logical. Since the source of energy for heating and electricity varies per country, an indicator in terms of energy or CO2 can differ significantly. This has the disadvantage that the same set of measures will have a different reduction factor, depending on the country where it is applied, because of the different sources of energy for production of heat and electricity.

Another consideration is the targeted audience. If the consumer is to be addressed, communication in terms of economy is probably the most effective. This can be realized by calculation of the operational costs, stemming from energy usage. For (local) authorities and project development, communication in terms of CO2-emission and/or energy usage is more common.

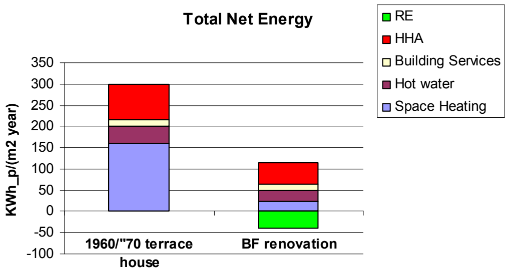


Figure 2.2-1
The energy profile before and after renovation

Last but not least, there is the issue of reference; to be used to calculate with what factor the renovation concepts has reduced the energy demand. The issue of reference has different dimensions:

The following energy uses are taken into account:

- Only building related for heating
- All building related energy (thus also including auxiliary energy for ventilation systems)
- User related energy, which can be influenced by a renovation package (e.g. infrastructure for hot fill, smart meters)
- User related energy, which is independent of renovation
- Off-site production (e.g. community systems)
- The sum of all of the above
- To what state is the new energy usage compared, possibilities are:

A reference amount, equal for all renovation concepts (e.g. average energy usage in existing buildings in a certain reference year)

The energy usage of the building to be renovated

- Primary energy or final energy: the use of renewable energy (and what it is used for) influences the outcome (see also the document on energy terms)

To illustrate the influence of the above aspects on the possible outcome for an energy reduction factor the case of renovation concept for a terraced house from 1970 in the Netherlands is taken. In this case a rigorous set of measures is adopted. This implies:

- Minimized demand for room heating (insulation and infiltration), domestic hot

water (using heat recovery) and electricity (e.g. standby killers)
- Use of Renewable energy (solar thermal and/or PV)

The energy profile before and after renovation is illustrated in the Figure 2.2-1.

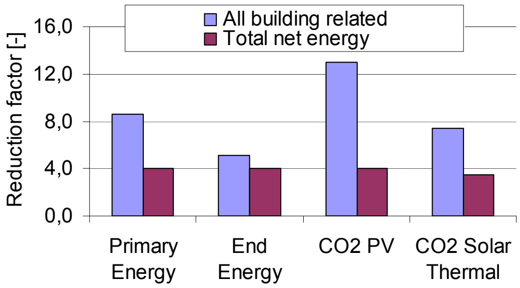


Figure 2.2-2
Primary energy, final energy (or site energy) and CO2 used as energy indicator and related to all building related energy and total net energy

The reduction factor for this concept might vary between 3.5 and 13, depending on the reference chosen. This is illustrated in Figure 2.2-1, where primary energy, final energy (or site energy) and CO2 have been used as energy indicator and related to all building related energy and total net energy. The figure also illustrates that the factor is influenced by the type of renewable energy that is used, since the CO2 emission factor for electricity and heat (in this case gas) can be very different.

2.2.3 Proposed energy ambition indicator

As illustrated above the reduction factor is highly depending on the reference and used definition.

It is proposed for Task 37 that the reduction factor that is at least communicated in all cases, will be the quotient of the total net primary energy (in kWh per square meter useable floor area) after the renovation and the total net primary energy as calculated as an average value for an existing building of the building stock in the EU in 1990. The latter value is differentiated between building types: multi-family, terrace house, semi-detached and detached.

The off-site energy production is only taken into account if the costs for production are directly linked to the renovation project (e.g. wind production unit owned by association of private building owners).

The reasons for this are:

- It allows for comparison between different sets of renovation measures, independent of the country where it is applied
- It does justice to the fact that the growing need for electricity needs to be addressed and solutions in this area should be embraced

2.3 Restructuring of floor plans / decisions

Nadja Grischott

2.3.1 Survey of the existing situation

In retrofit often the floor plans of existing buildings doesn't fit any more into actual market needs. Therefore the actual layouts should be analysed.

A survey on existing buildings should comprise the following aspects:

- floor layout not according to modern standards (small rooms)
- state of construction and material
- structural constitution
- structural damage (mould, condensate)
- mechanical installations (inefficient, old)
- requirements by the owner
- need for different apartment type
- reduce costs for energy

2.3.2 Options to interfere with existing building fabric

Based on the above mentioned analysis, three different phases could be defined in the process of floor plan restructuring:

Phase I: improve building envelope and technology

- maximize solar gains: keep windows or enlarge
- minimize heat losses: windows, facades, ceiling to basement and roof partly or brand-new insulated
- use of up-to-date technology on mechanical installations: heating, ventilation, hot water, replace electrical devices
- consideration of overall energy balance: grey energy, energy to run the building, deconstruction
- integral planning: team, synthesis (architecture, technology, ecology)

These measures often could be applied without interfering too much with the existing building structure.

Phase II: adaption of the floor plan to new requirements

In addition to the measures in Phase I the following restructuring of the floor layout might be feasible based on the analysis. Depending on the inhabitants demands the following measures are worthwhile to mention:

- improved floor layout (larger rooms, kitchen re-organization)
- reduction of room numbers and flat size to adapt to changing societies needs: Increasing single households, increasing people's average lifetime
- restructuring of balcony layout
- Integration of elevators and other measures to be "handicapped ready".

Phase III: addition of new rooms i.e. roof

Phase III could be seen as combination of phase I, phase II and the enlarging of space by adding new annexes to the existing buildings or heightening by replacing the existing roof.

2.3.3 Examples and feasibility of the renovation

For three different urban situations (Type1: Downtown, Type 2: Suburbia and Type 3: Garden City) examples from the greater Zurich area were chosen, documented and analysed regarding their economical feasibility. The results are given in Figure 2.3-1 (existing situation and Phase I), Figure 2.3-2 (phase II) and Figure 2.3-3 (phase III). The following conclusions can be drawn:

- Phase 1: low costs for building envelope and technology – surplus due to modernisation (increased comfort), however: no extra income as there is any extra space to rent out
- Phase 2: moderate costs for improving floor layouts, building envelope and technology – surplus due to new layouts with increased comfort, no extra income as there is no extra space to rent out
- Phase 3: high costs for extension, improving floor layouts, building envelope and technology - surplus due to new layouts with increased comfort and extra income for larger apartments

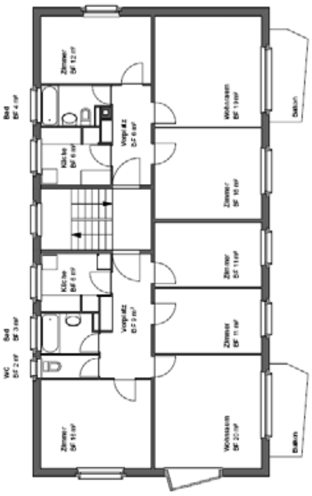
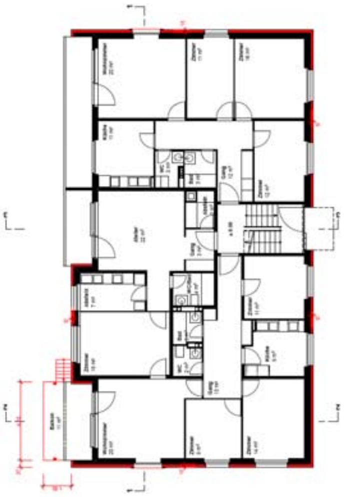
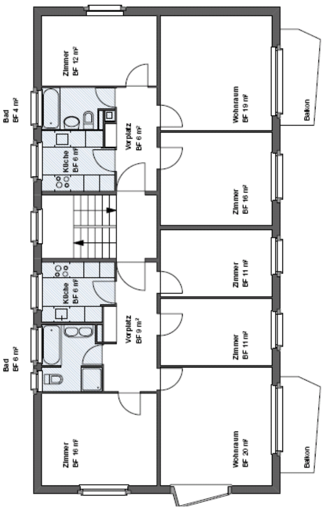
Type 1 Downtown	Type 2 Suburbia	Type 3 Garden City
Existing Situation		
		
Phase 1		
		
	Investment 500’000.- SFr. Improved comfort	Investment 770’000.- SFr. Improved comfort

Figure 2.3-1
Feasability of floor plan changes: Existing Situation and Phase I

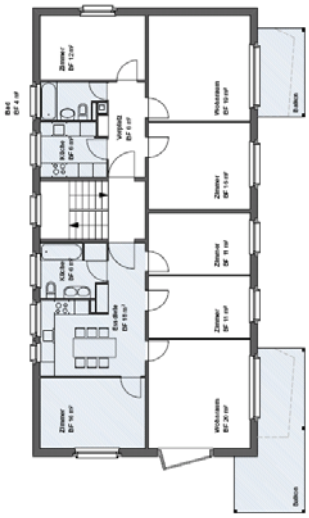
Type 1 Downtown	**Type 2 Suburbia**	**Type 3 Garden City**
Phase 2		
 Investment 2’560’000.- SFr. 1.5 Room-flat 3.5 Room-flat Lettable area 780m² Rental income 220’000.- Return on investment 5.4 %		 Investment 810’000.- SFr. + 75’000.- SFr. (balconies) 3 Room flat 4 Room flat
 Investment 2’480’000.- SFr. 6.5 Room-flat Lettable area: 782m² Rental income 240’000.- SFr. / year Return on investment 5.4%		

Figure 2.3-2

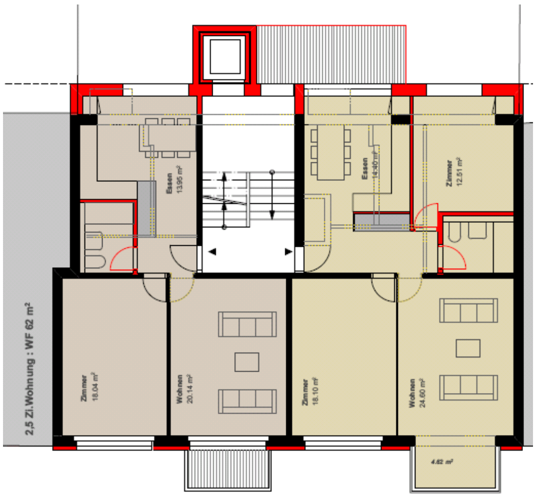
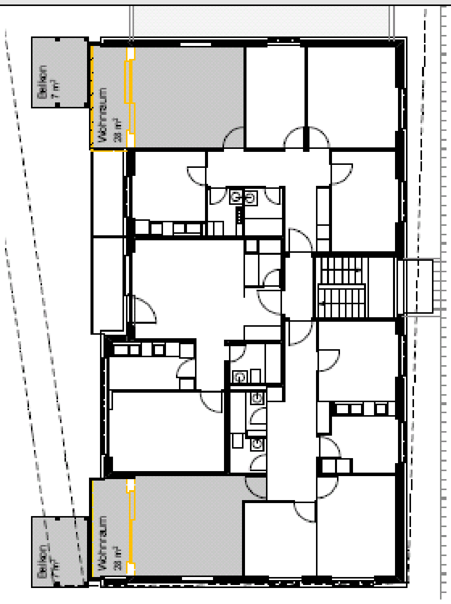
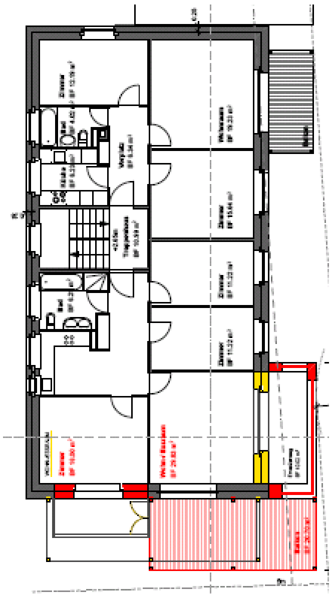
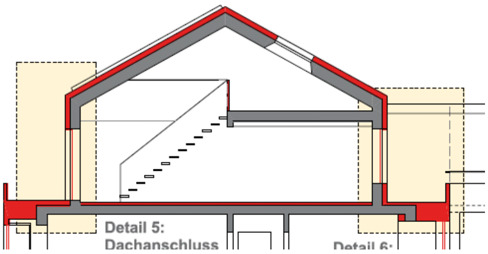
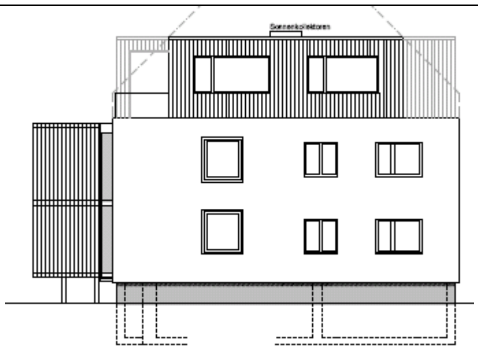
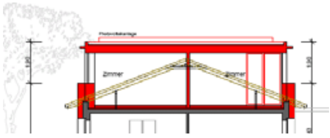
Type 1 Downtown	**Type 2 Suburbia**	**Type 3 Garden City**
Phase 3		
		
Investment 2’300’000.- SFr. 2.5 Room flat 3.5 Room flat (combined kitchen/living room) plus 67m²	Investment 650’000.- SFr. 4.5 Room flat 2.5 Room flat plus 32 m²	Investment 950’000.- SFr. 3 Room flat 4 Room flat (large living room) plus 30m²
Additions		
		
Investment 600’000.- SFr. New luxirius flat under the roof 4.5 Room flat plus 51m²	Investment 650’000.- SFr. 4.5 Room flat 2.5 Room flat plus 112m²	Investment 620’000.- SFr. New attic 4 room flat plus 104m²
Phase 3 and Additions		
Total Investment: 2’900’000,- SFr. Lettable area 878m2 Rental income 250’000.- Return on investment 5.7%	Total Investment: 1’300’000.- SFr.	Total Investment: 1’570’000.- SFr. Lettable area 495m2 Rental income 195’000.- SFr.

Figure 2.3-3
Feasability of floor plan changes: Phase III and additions

2.4 Users participation as success factor for advanced housing renovation – examples from Austria

Claudia Dankl

Every technology has to be applied by users, thus the technological system becomes a socio-technical system. In low-energy and passive housing – newly built or refurbished – technological knowledge and know-how of users is required increasingly. Inhabitants of low-energy and passive houses have to deal with a lot of technological questions and undergo learning processes. The participation of users in planning and building processes raises the likelihood for appropriate handling of the building and its technical equipment later on. In successful cases participation can result in users' support for innovative technologies, their adequate understanding of the technical building equipment and of the way how to use it. Thus user participation in refurbishment processes can help to make innovation successful, as the innovation term has to be viewed not only in the context of ecology and economics but also from a social point of view. In the Austrian research programme 'Building of Tomorrow' the acceptance of technologies by users was an important topic. Three projects dealt with users' participation in sustainable refurbishment processes. The following pages provide an overview and a short summary of some of these research and demonstration projects.

2.4.1 Sustainable housing concepts and attitudes of users

The research project 'Experiences and attitudes of users as a basis for the development of sustainable housing concepts with high social acceptance' divides user participation during the building process in four phases:

1. Research and development,
2. Planning,
3. Construction
4. Use of the building.

For each of these phases, answers to the following questions are required:

- Which topics are appropriate for a participation process?
- Which methods lead to reliable results?
- Which groups of users should be integrated?

Results of the above mentioned research project give reason that for the early project development phases only participation of experienced user groups is appropriate. Approaching the point of realisation of a building, it becomes increasingly reasonable to include all prospective users in the planning process.

More information at

http://www.hausderzukunft.at/results.html/id1764

2.4.2 Sanierung PRO!

The goal of the project has been the development of a guideline, which supports builders, planners or consultants to organize and monitor inhabitants' participation in renovation processes of multi-storey buildings.

Renovation processes are always interferences in existing constructional and social structures. Planners and builders who work with these structures have to be aware, that renovation is a dynamic process, which has to be optimized constantly. Participants in the construction process are manifold: builders, planners and process consultants as well as actors of politics and administration. In an ideal renovation process each group reflects on its concepts at the experiences of past renovation projects, in order to develop a high degree of process consciousness. Professional communication and open information towards inhabitants are therefore essential not only during the refurbishment phase, but during the entire term of lease. Due to the high complexity of renovation measures the project team of 'Sanierung PRO!' developed different communication strategies for the different target groups involved:

Target group builders and planners

- Current and open information increases the understanding of inhabitants for the building process as well as inhabitants' identification with the object
- Current enquiries about the constructional conditions of objects – collected e. g. in sort of a building data base – and data on the inhabitant structure are crucial for developing an optimal renovation strategy
- A renovation strategy and different options for action have to be developed before the start of the inhabitant integration
- Preliminary talks with inhabitants provide to the success of the renovation process
- The builder decides on the character of the inhabitants' integration – information,

consultation or participation – and informs the inhabitants constantly
- Continuity and a high degree of social competence in the project team and among the contact persons decrease conflicts

One recommendation of the project is to establish a 'builder's academy' as possibility for institutionalized exchange of experiences between builders.

Target group politics and administration

- Flexible models of housing subsidies dependent on basic conditions
- More flexible time periods for housing subsidies
- The requirement of 100 % agreement of inhabitants must not be an exclusion criterion for good renovation concepts
- Cushioning of social severities by combining subsidies for objects and subjects in the context of renovation measures (also of individual measures)
- Subsidies and grants for necessary pre-enquiries (in regard to built volumes, inhabitant structure) as well as process costs of inhabitants' participation (e.g. external consultation).

One result of the project was a guideline – available in German – to support builders, planners or consultants in the organization and monitoring of inhabitants' participation in renovation processes of multi-story buildings (Figure 2.4-1). More information at

http://www.hausderzukunft.at/results.html/id3814

2.4.3 Cooperative Refurbishment

In this project a model of user participation – for owners and tenants – in advanced renovation of multi storey buildings was developed. In addition demands of inhabitants during renovation processes in multi-storey buildings were studied and exemplary participation processes in renovation projects were implemented. Extensive renovation processes in Austria require the legal consent of residents. This is particularly true for energetic and ecological improvements. An early and systematic involvement of inhabitants could help to avoid many problems concerning the lack of support for extensive renovation often encountered by project managers.

User participation can also be seen as a chance for inhabitants to actively evaluate their own residential environment. This usually results in high acceptance and identification with the chosen solutions. But also extensive forms of participation do not guarantee the implementation of sustainable concepts. Three main arguments for participation in planning processes are called for:

- Legitimation: Through a broad process of opinion-forming it is guaranteed that the interests of occupants are taken into consideration and decisions are democratically authorized.
- Efficiency: People are experts of their everyday life. Considering this knowledge in planning processes can help to avoid objections or changes later on.
- Identification: Informing and integrating occupants in an early stage of planning processes may contribute that people accept and identify with the results.

Groups of actors

In multi-storey buildings different groups of actors are involved in renovation processes. The project characterizes the most important participants and their roles as follows

- Housing companies: In the first place housing companies must be willing to include occupants in the process of renovation.
- Occupants (owners/tenants): At least a certain number of residents are usually interested in selected questions. Offers to participate in planning processes have to be agreed upon the residents' needs in regard to the dimensions space and time.
- Building companies: Beginning of construction works is not the end of residents' participation. Professional contact with residents during the construction phase, responding flexibly to wishes and needs, is an important part of renovation processes.
- Social environment: Surrounding neighbours are also important in renovation processes. It is necessary to minimize the inconveniences for the neighbourhood and to inform neighbours about phases of the construction process.
- Subsidising institutions: In Austria institutions that are financially supporting the renovation project are also involved in the building process. They can influence the arrangement of the renovation processes via general guidelines.

Housing companies have to move within prescribed legal framework. In Austria the

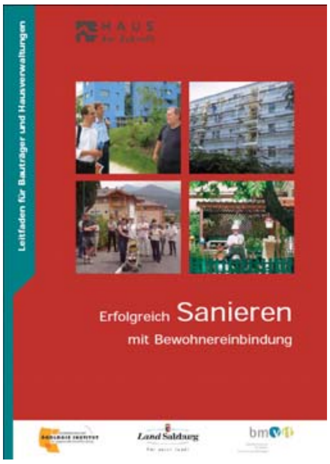


Figure 2.4-1
Cover of the brochure of the project Sanierung PRO!, (http://download.nachhaltigwirtschaften.at/hdz_pdf/leitfaden_sanierung_pro.pdf)

residential property law ('Wohnungseigentumsgesetz') and the non-profit housing act ('Wohnungsgemeinnützigkeitsgesetz') define certain proceedings, which must be kept, e.g. duties to supply information, holding of information meetings in regular intervals, execution of inquiries and voting's with the occupants or complying with terms.

Four levels of participation

The project developed a model which offers residents possibilities for participation in all phases of the renovation. Based on Wilcox (1994) the project team distinguishes four levels of participation:

- Information: a one-way-communication from the housing company to the residents of a building to be renovated.
- Communication: At this level of participation a two-way-communication is established, a dialogue between residents and representatives of the housing companies or the facility management occurs; questions can be asked and answered reciprocally.
- Co-design: At this level residents can participate actively, they have the possibility to grapple with certain questions concerning the renovation process. Concrete ideas and solutions are being developed. The question, how results enter the planning process in reality, is open. A possible disadvantage of co-design can be the exclusion of less involved or less active residents.
- Co-decision: At the level of co-decision occupants really take responsibility. The project team distinguishes between collective and individual options of co-decision. The second one refers to changes in single apartments whereas collective co-decision deals with questions, which refer to larger units, e.g. the whole building.

Flexible model of participation in different phases of the renovation process

The model developed within this project is kind of a tool kit. Elements and methods for different phases of renovation processes and levels of participation can be chosen, applied and combined. Suggestions for possible methods for inhabitants' participation along the different phases of a renovation process are:

1. First decision

Written information shall be given to residents, excursions to retrofitted buildings can be offered (Figure 2.4-2), workgroups or round tables can be installed. Further methods are talks and interviews with occupants, the edition of special house-newspapers or information via internet. Also cost intensive participation methods like future conferences or citizen juries could be applied for large projects. At a future conference participants selected from all interest groups affected draw up programmes and action plans for forthcoming projects in line with a predetermined schedule. In a citizen jury individuals selected at random draw up a 'citizens' assessment' – or in case of a renovation process an 'inhabitants' assessment' of a particular issue, based on their own experience and knowledge. Experts provide assistance for specialized aspects. For the duration of the citizen jury participants are released from their everyday obligations.

More information on participatory methods can be found at

www.partizipation.at/methods.html

Figure 2.4-2
During excursions to existing passive house projects inhabitants can inform themselves about new technologies

2. Stock check of the building

Occupants can be included in building inspections. They can be invited to evaluate and assess the building and to make suggestions for improvement.

3. Rough planning

Information and communication are of special importance. Methods are residents' meetings or workshops with experts that give information on renovation variations. Also small workgroups and focus groups can be established. In a focus group 8 to 15 persons take part in a chaired discussion on a predetermined topic; this can lead to the development of a cohesive group view. The method originated in the field of market research, where it is used to test products and advertising strategies.

4. Detailed planning and call for tender

Cooperation with and of occupants is possible in form of a residents' advisory board. The board can be included in important decisions like selection of building companies.

5. Phase of decision

In this phase especially methods for decision and voting processes will be applied, like written questionnaires or meetings with occupants.

6. Construction phase

An occupants' committee to accompany and control construction works can be installed. Furthermore the on-site presence of the housing company and the availability of its contact persons are very important, this can be reached by establishing an on-site-office, regular consultation hours combined with good information and communication policy. The above-mentioned residents' advisory board and occupants' committee can be very important in this stage of renovation as well. At the end of construction works celebrating can be recommended as a good method.

7. Phase of reflection

At the end of a participatory renovation process occupants should be allowed to control the costs. An evaluation about what has been done well and what could have been done better in the process is a good conclusion of the process. During renovation processes housing companies have to move within the legal framework and must therefore offer prescribed ways of participation. E.g. they have the duty to supply information, to hold information meetings in regular intervals, to make inquiries and a voting with occupants or observe deadlines. The project shows possibilities to enhance participation in renovation processes, e.g. moderation, inspections, excursions, check lists for occupants, focus groups. These methods can be selected and applied depending upon situation and basic conditions. More information at:

http://www.hausderzukunft.at/-results.html/id2819

2.4.4 PARTI-SAN

The full title of this project is 'Facilitated decision-making procedures for sustainable renovation of residential properties – Participation in the renovation process. Concrete renovation projects were monitored and guidelines to optimise planning, information and decision-making processes during the renovation of residential properties were developed.

In practice the reasons for a failure of renovations in residences that contain freehold flats / condominiums can often be explained through lack of acceptance or different opinions amongst the owners, rather than through barriers of technical or financial feasibility. Inadequate procedures of planning, information and decision making are barriers for the implementation of comprehensive, innovative and sustainable renovation of residences. Important points for the integration of sustainable aspects in the renovation process are:

- cost efficiency for the implementation
- saving effects through the renovation
- user orientation
- improvement of living comfort for the residents

The project comes to the following conclusions:

- A high percentage of 'non-voters'hampers a decision in favour of an advanced renovation; therefore it is important to mobilize residents.
- Residents need appropriate and comprehensive information.
- Professional third party moderation and consultation for the residents meeting can be crucial, e.g. if there are existing conflicts among or with certain residents or if the building managers' basis for discussions with residents is not so good. In Austria usually the property management moderates the assemblies and one has to be aware that it acts in a double role. The important thing is that questions and problems of residents are taken seriously.
- An adequate framework for the residents' meeting can be a benefit for decisions in favour of an advanced renovation, e.g. an informative invitation as an incentive to participate or a thoroughly planned agenda of the meeting. Also opportunities for visualization may be of help.

- In Austria the programme klima:aktiv ‘wohnmodern’ offers a rough analysis consulting package for house owners and communities of residents, e.g. the participation of independent experts at residents’ meetings. The participation of external experts can be a good measure to convince residents.

www.wohnmodern.klimaaktiv.at/ (in German)

http://www.hausderzukunft.at/results.html/id2806

2.4.5 Experiences from demonstration projects

Additional experiences with residents’ participation in renovation processes have been made within two demonstration projects,

Renovation of the multi-storey-building ‘Makartstraße’ in Linz

During the planning phase information was given to residents through organised meetings with presentations and discussions. A high grade of acceptance for the project from all tenants could be reached. Shortly before the renovation was finished another meeting with tenants was held, where the way of living in a passive house was explained once more. People had the opportunity to exchange experiences. Another research project (www.zuwog.at) even gives the recommendation to make trainings with inhabitants as far as new technologies like ventilation etc. are concerned. In the project Makartstraße the extra costs of the renovation could be held low because of housing subsidies for the renovation based on the passive house concept from the Federal State of Upper Austria (‘Oberösterreichische Wohnbauförderung’) and with additional support from ‘Building of Tomorrow’. There were no additional monthly charges for the tenants. Thus a very high acceptance of the renovation project could be reached. More information at

http://www.hausderzukunft.at/results.html/id3951

Demo project brochure of Task 37

http://www.iea-shc.org/publications/downloads/task37-Linz.pdf

Renovation of the multi-storey-building ‘Klosterneuburg/Kierling’

Construction works for this renovation projects were still pending in July 2009 due to objections of neighbours. Nevertheless the planning phase has been finished with extensive participation of residents.

Figure 2.4-3
Celebrating together after finishing the renovation work is a very important milestone for residents and project owners.

Figure 2.4-4
In the project in Klosterneuburg/Kierling inhabitants were informed very well and several meetings were held.
source: Architekt Reinberg

The project team worked with tenants in one-to-one-interviews in individual sessions, information about costs, increase of monthly charges and the timetable of works and exposures to noise, dirt, limited access during building work has been given to the tenants (Figure 2.4-3 and Figure 2.4-4). An excursion to a multi-storey building that had been renovated to passive-house-standard took place in 2006.

Participants could visit two apartments of the refurbished building and talk with inhabitants in a meeting organized in an inn afterwards. Once the work on the site will start, further measures are planned like

- information and one-to-one-sessions to individual adaptations – e.g. tenants can make an agreement with the housing company BUWOG and arrange individual renovation wishes with skilled craftsmen working at the site (at lower costs than usual)
- organisation of tenant-meetings with planners and responsible persons
- compensation in the height of the rent of one month during the construction time
- Support and information for tenants during construction time.

More information and Demo project brochure of Task 37 at

http://www.hausderzukunft.at/results.html/id4559

http://www.iea-shc.org/publications/downloads/task37-Kierling.pdf

2.4.6 Conclusions

Increasing the rate of advanced housing renovation is an important goal in regard to climate protection. A lot of objects to be refurbished are inhabited by tenants or owners. In this context the legal framework for renovation processes is very important.

In case of residential properties it is impossible to realise an advanced renovation process without acceptance of the owners. One way to reach acceptance of many occupants are financial incentives for renovation measures. Another important focus can be user orientation and the inclusion of all relevant stakeholders in the renovation process. The mutual dialogue of the project consortium on the one hand – from developers to the craftsmen – and inhabitants on the other hand can be a key to successful housing renovation. Advantages of renovation measures and new technologies can be shown and explained. Information and decision processes become more transparent. The knowledge of inhabitants can be of great use in the renovation process. If inhabitants see their needs and wishes considered in the planning and construction process they will more likely accept the whole concept and following inconveniences during the construction period. Thus user participation in renovation processes can lead to a win-win-situation for everyone.

This chapter is carried out in the framework of the Austrian participation in the Energy Technology Programme of the IEA and funded by the Austrian Ministry for Transport, Innovation and Technology.

2.5 Economics of high performance old house renovation projects

Berthold Kaufmann, Witta Ebel

2.5.1 Introduction and Summary

Conclusion in advance: Building of high thermal performance houses or to be precise, Passive Houses is by now reasonable not only with respect to ecologic issues, but as well regarding financial yield. *In addition*: The refurbishment of old buildings using components known and developed during the last ten years for new built Passive Houses is a realistic option, because rather high energy savings are possible for old buildings as well, if the design is worked out properly following the conception.

There are some extra tasks to be solved for old buildings, e.g. thermal bridging at the edge of the cellar ceilings and -walls. But there are no real barriers in principle which are not to be overcome when doing a renovation.

The high thermal quality of components of the building envelope does not only have a high impact on the energy demand of the building, but they determine as well thermal comfort feeling and thus the quality of living. Optimized thermal insulation of walls, roof and basement or floor respectively, high performance windows with U-values better than 0.85 W/ (m²K), mechanical ventilation systems with high efficient heat recovery (85 % and higher) are described in detail in this book elsewhere. This chapter will show that an extra investment in thermally optimized building technology gives substantial added value for the building and a surplus for the user. Calculating costs of this extra investment and comparing this with costs of energy consumption during lifetime shows clearly that high efficient technology either pays back within lifetime already now or is just before a break even with respect to cost considerations.

Figure 2.5-1
Well insulated elements of building envelope are important for high thermal comfort in new buildings and old house renovation.
Enlarging insulation layer thickness of a sloped roof by doubling the rafters. The gaps are filled with mineral wool.
Foto: PHI

All high thermal performance components in combination may result in a so called high thermal performance house, e.g. a Passive House or a comparably renovated building. These buildings, as some examples are shown in this book and in the framework of IEA Task 37, have proven to be cost effective in total.

Therefore, with respect to the whole lifecycle of the buildings, the total lifecycle costs (investment costs and the energy costs) during

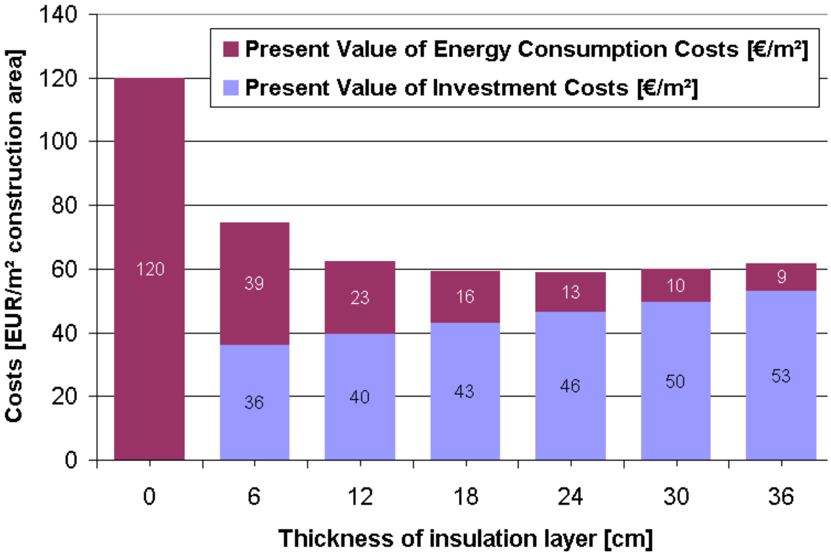


Figure 2.5-2
Total costs (Present value) for a compound thermal insulation layer in the wall. The energy consumption costs and the investment costs are summed up and are depicted as a function of insulation layer thickness [Feist 2005].
Area specific values [€/m²] here are related to the construction area.

lifetime will be at an optimum for high performance Passive House refurbishments. The costs for the Passive House components will decrease because of higher market penetration (mass production) and the better experience of planners and craftsmen.

Additional considerations show clearly that a highly efficient energy consumption infrastructure – in our context the total of all buildings to be heated – is the basis for the option to supply a considerable fraction of buildings with renewable energy sources [16][Kah/Feist 2008], [12] [Kaufmann/Feist 2003] such as solar thermal heat, solar PV, hydro-power, wind-power and biomass.

2.5.2 Basics: calculation methodology and financial boundary conditions

The economic effectiveness of actions that improve thermal performance of a building and hence decrease its heat losses can be estimated for several components of the building. To calculate the financial effort of thermal insulation layers, high performance windows, the mechanical ventilation system with heat recovery and the heat supply system, the costs for the different actions and components are calculated as a 'price' for the saved kWh of heating energy. This price can be easily compared with the actual price for the delivered end energy. In this chapter an average net price (without VAT) of 0.056 €/kWh end energy is assumed to be realistic for the next 10…20 years. For the insulation layer the cost of the supplied or saved heat respectively has to be taken into account. This is higher by the efficiency of the supply system (90 %) and the costs for electricity to drive pumps etc. The overall costs for the heating energy is therefore calculated to be 0.084 €/kWh on the basis of a present (2010) end energy price of 0.07 €/kWh [10] [Feist 2005], [17] [Kaufmann 2005] and [11][Kah/Feist 2008], see Table 2.5-1. The price for conventional electricity is assumed to be 0.22 €/kWh. Please note, the price for 'renewable' electricity will be most probably higher [11] [Kah/Feist 2008]. In addition the costs for the supply system (radiators) decrease significantly with the lower heating load of the supply system, therefore less radiators are needed (Table 2.5-3).

In some studies there are used numbers for the payback period of an investment. In the context of innovative products for high performance housing and renovation this intends, that any action or product that saves energy, pays back within its lifetime. If this is not the case e.g. for a mechanical ventilation system, the payback times get longer than lifetime of the components (e.g. 20…30 years). These results are correct, but cannot really help making decisions, because a comparison of costs is not possible. On the other hand, the economical return after the payback time is not valuated. Therefore we do not argue with payback times.

Annual Rate of interest	3.0 %		**real rate, adjusted by inflation**
Calculation Time of interest	20 a		**with constant rate of interest**
Lifetime of Components	20 a		**mech. ventilation domestic hot water, etc.**
"	30 a		**windows**
"	50 a		**thermal insulation of wall and roof**
residual value after 20 a	23.3 %		**(30 years lifetime)**
residual value after 20 a	42.2 %		**(50 years lifetime)**
Price for end energy	0.070 €/kWh		**oil, gas, district heat, not electricity**
Total costs for supply of heat	0.084 €/kWh		**explanation see text, not electricity**
Price for electricity	0.22 €/kWh		**end energy**
Climatic region	74 kKh/a		**mean value for Germany**

Table 2.5-1
General data for cost calculation. The assumed lifetimes exceed the financial calculation time with fixed rate of interest, resulting in a residual value of components at the end of calculation time, see tables and text.

Knowing about the costs of the saved kWh is the better method, because it can help making reasonable decisions, see Figure 2.5-5: If the extra costs for an energy saving action such as an optimized thermal insulation layer or a good window frame with triple glazing are lower than the financial effort for delivery of heating energy, the financial effectiveness is obvious. If on the other hand the extra costs for such a component is higher with respect to its energy saving potential (€/kWh) than the actual price for energy, the architect, planner or the investor can make a considerable decision by comparing the costs. Using this method he is able to take into account an additional 'extra benefit' of an action or component besides its only energy saving potential. So displaying the results by the price of the saved kWh is a very transparent manner, which allow making decisions by comparing costs of different actions in detail, see Figure 2.5-5.

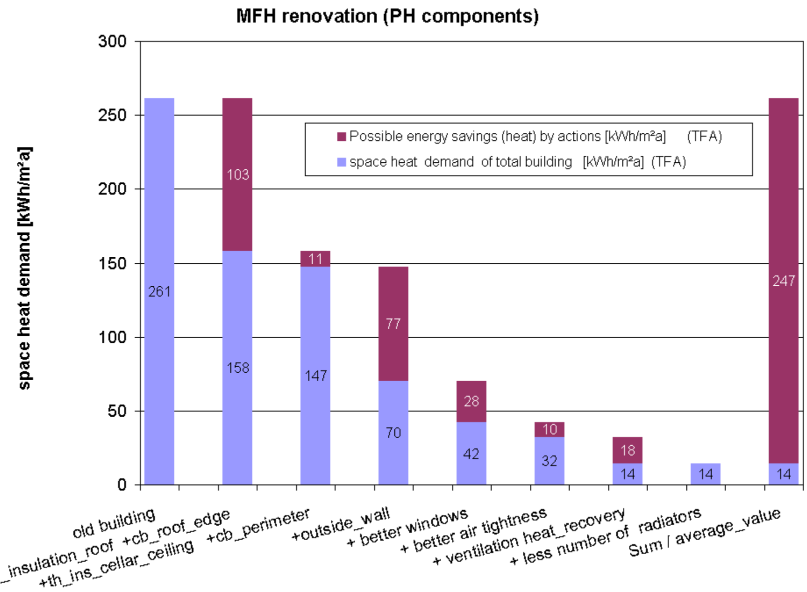


Figure 2.5-3
Heating energy demand for a renovated building. 'Step by step' the several actions were added to show the response of the energy balance.

The calculations in this chapter are based on the dynamical method for calculations of capitalized values or present values respectively [1][AKKP 11]. The boundary conditions for the calculations are assumed as follows (Table 2.5-1). The medium (real) annual rate of interest for an investment in the last decade was about 3.0 % where the inflation rate of about 1.7% is already taken into account. The financial calculation time with a fixed rate of interest is assumed to be 20 years which is shorter than the lifetime of the most building components used in middle Europe today. This assumption results in a residual financial value at the end of the calculation period, which decreases the actual cash value of the investment costs significantly [10][Feist 2005], [11][Kah/Feist 2008], [19][Steinmüller 2005].

2.5.3 Costs and extra costs for high thermal performance components

Two questions as an introduction: (1) what are the costs of doing 'nothing' with respect to thermal performance of buildings especially providing no thermal insulation for a new

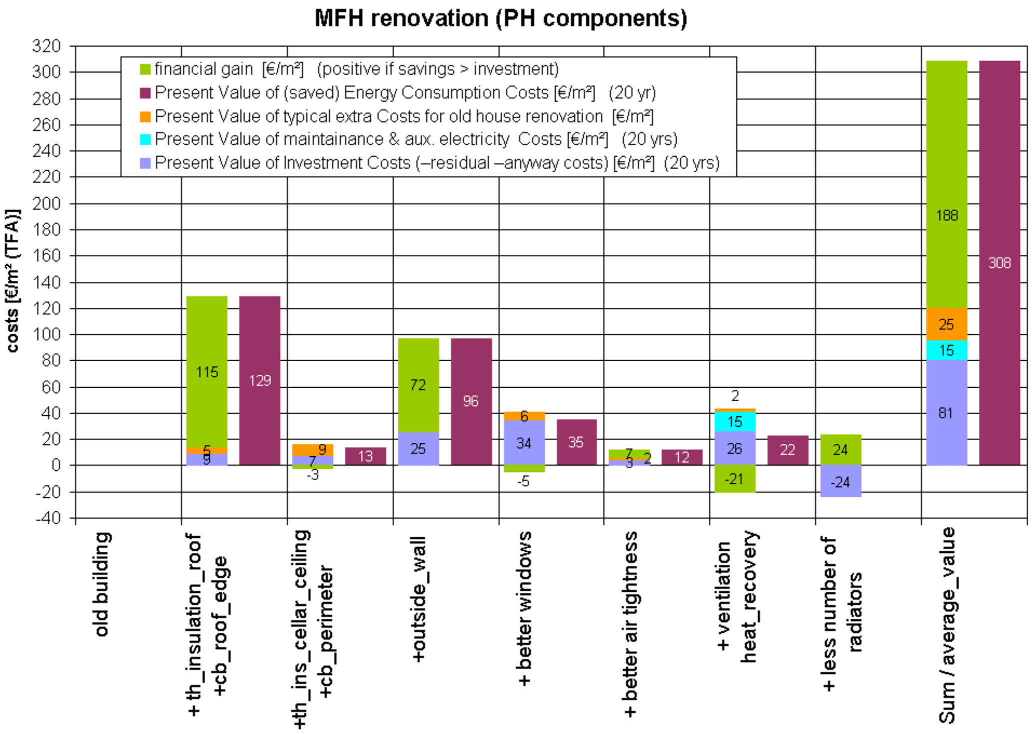


Figure 2.5-4
Economic values for the actions of energy savings for a representative renovation project. For each step building costs and the savings in heating energy demand over 20 years is shown. Extra costs specific for old house renovation is shown by orange bars, see text. The difference between investment and savings is the return or reduced loss realized over 20 years. Specific values by m² treated floor area.

building? (2) What are the costs for a new rendering for an old house? Looking at the graphs in the following sections the answer is really simple: Doing nothing may become rather expensive. The running costs that a square meter of an outside wall which is not thermally insulated will cause during its lifetime are significantly higher than the total costs for an insulation layer, see Figure 2.5-2.

The examples given here grew up in the context of high thermal performance house especially Passive Houses and refurbishment projects where similar components have been used. The present value of investment costs compared to the energy consumption costs over a period of 20 years are shown in this section for the most important building components, see Figure 2.5-4 and Figure 2.5-5.

The climatic boundary conditions for the examples are assumed to fit for the region of North and Central Europe: Germany, Austria, and Switzerland. A mean value for Germany to characterize the climate is a heating degree day of 74 kKh/a. This value will be higher on the mountains and valleys of the Alps and in the (arctic) Scandinavian countries. Higher values for heat degree hours will obviously lead to a higher energy saving potential. The use of 74 kKh leads therefore to a careful estimate of the financial potential of high thermal performance buildings.

Only the 'energy related' costs have to be taken into account when calculating the total costs of an energy saving action. An intact rendering on the outer wall of a building is necessary in any way. So these 'anyway costs' for the repair of the rendering when doing a renovation may be subtracted from the investment costs, see Table 2.5-3. The energy losses and the related running costs can be calculated directly by using the U-value of the construction times the degree day number (74 kKh/a) of the relevant climatic region. The thermal insulation layer is assumed to have a lifetime of 50 years, see Table 2.5-1.

This idea is most relevant for old house renovation because it leads directly to the principle of combination of actions which have to be done 'anyway' when renovating an old house, see below.

The optimum scenario at present energy prices is an insulation layer of about 18 to 24 cm thickness which costs about 0.030 € per saved kWh. But the cost function in Figure 2.5-2 is rather flat around the minimum. Therefore the 'future scenario' with a layer thickness of 30 cm or even 36 cm which is suitable for Passive Houses, has only slightly higher costs of 0.034 € per saved kWh. This is more than 40% below the present (2010) price for end energy of 0.070 €/kWh [11][Kah/Feist 2008]. For comparison: A layer thickness of 15 cm with a U-Value of about 0.25 W/(m²K) is needed according to the present national building code in Germany [8][EnEV 2009].

As can be seen clearly in Figure 2.5.2 the action 'additional thermal insulation' is in any way economically appropriate. Doing nothing is in any case more expensive: All thermal insulation scenarios have lower total lifecycle costs than the one with no thermal insulation. What is more: thermal insulation is by far the cheapest action for energy savings at all. With respect to life cycle costs, Passive House windows are also economically feasible. Regarding a complete renovation project (Figure 2.5-3) the ventilation system with heat recovery – which is more expensive but absolutely necessary for good buildings – is financed by the return of the thermal insulation at the outside wall and by the savings because less radiators are needed. Thus the average value for the price of saved kWh for all the project is quite low (Figure 2.5-5).

2.5.4 Insulation layer for the roof

Thermal insulation of the roof is by far the most economic action that can be done when building a house. The static structure in form of the rafters is needed anyway and can be enlarged by simply choosing higher rafters at moderate extra costs [10][Feist 2005] [11][Kah/Feist 2008]. For renovation the rafters can in most cases be simply doubled by additional rafters on top. But static needs should be checked carefully. The enlarged gap between the rafters can be filled by mineral wool or cellulose fibre, see Figure 2.5-1.

The costs for a thermally insulated roof are therefore really low under the assumption that roof tiles and slats are needed anyway. So only the costs for the extra layer thickness have to be considered and so the economic effectiveness is obvious even for the 'future scenario' with rather high insulation layer thickness. A thermal insulation layer thickness of about 40…50 cm in the roof is suitable for Passive Houses. This is well confirmed by the economic and ecologic results see Figure 2.5-5.

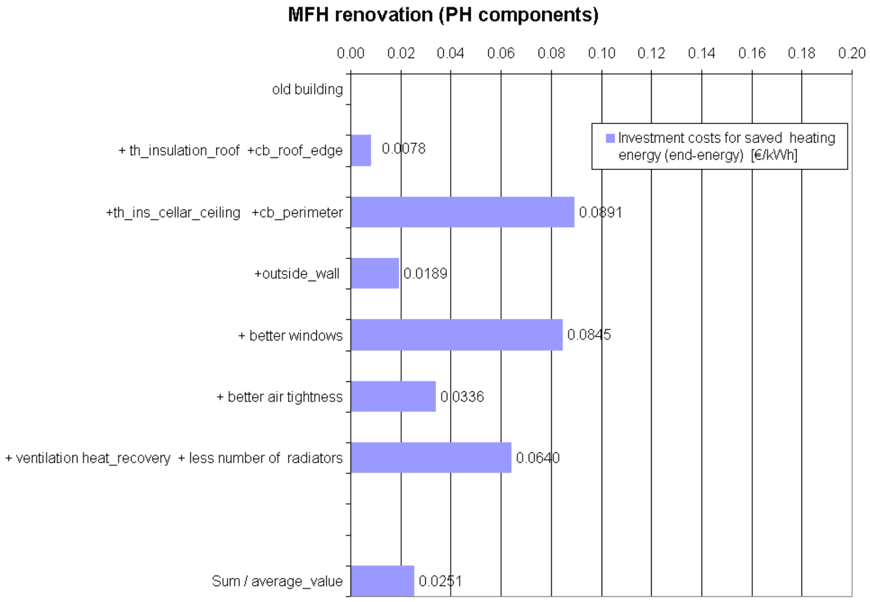


Figure 2.5-5
Investment costs of energy saving actions, calculated as €/kWh, explanations see text.

2.5.5 High performance windows

Windows are one of the valuable and hence high cost components for high performance houses. Newer cost evaluations [11][Kah/Feist 2008] with data of realized renovation projects dated of 2006 have given prices for Passive House quality windows (U_w = 0.85 W/m²K) with frames made of plastic profiles of about 370 €/m² (window area). For windows with wooden frames the prize goes up to about 450 €/m².

By the way: higher prices for windows are possible, but this is due to other qualities like choice of materials or surface quality or architectural design. These higher costs may therefore be excluded from our investigation as we want to check if there is a 'low cost' economic solution available. These costs (415 €/m², Table 2.5-3) have to be compared with standard windows available according to the local building code (U_w = 1.6 W/m²K). Such standard windows are presently available for about 320 €/m² window area. All cost data are for Germany that we chose as paradigm, please check for data in other countries.

The difference of these values thus 105 €/m² can be used to check if Passive House quality for windows is economically reasonable. So not the full price of a window, but only the amount exceeding the price of a window which is needed 'anyway' for a renovation, see the remark on anyway cost evaluation below.

For the special conditions of renovation projects it may be necessary to prepare the reveal of the window to place the new window outside the wall properly in the insulation layer to avoid too large thermal bridge effects. Costs for that preparation are estimated by about 40 €/m² window area, see Table 2.5-3. These costs are denoted in the graphs as 'specific extra costs for old house renovation' to be able to compare new house construction and renovations.

2.5.6 Detailed redesign of thermal bridges for renovation

Avoiding thermal bridges for new buildings is not a materialistic component that causes high costs. It is primarily the task and the genius of the planner. The thermal separation of the raising wall above the cellar or the ground plate of the house needs special materials to reduce the thermal bridge effect there to a minimum. Most thermal bridge effects of new buildings can be removed by stringent planning principles which avoid materials like steel or aluminium with very high thermal conductivity to come through the thermal insulation layer [20][Schöberl/Hutter 2003], [3][AKKP 24], [2][AKKP 16].

The situation is quite different for old house refurbishment: especially for the vertical walls of the cellar, no easy thermal separation insert can be added. Therefore the thermal bridges can only be 'defused' as good as possible by wrapping the wall from both sides inside and outside with insulation. For detailed graphs and description see the section about thermal bridges in this book, see one example in Figure 2.5-6. The costs for these 'wrapping'

Table 2.5-2
Parameters of building envelope components

	wall, roof, floor, cellar ceiling (average value)		windows and doors (average value)	ventilation system	air tightness
	U_{opak} [W/(m²K)] (thickness *)		U_w [W/(m²K)]	η(WRG)[%]	n_{50} [1/]
old house	0.6 to 1.4 (70 mm)		2.	only windows 0%	5.0
German building code (EnEV 2009)	0.25 (145 mm)		1.3	controlled exhaust air ventilation system 0 %	1.5
Passive building	0.1 to 0.15 (300 mm)		0.8	75 to 92 %	0.6 and better

**) average thermal insulation layer thickness with an assumed thermal conductivity of λ= 0.0350 W/(mK)*

are assumed to be about 75 €/m of perimeter of the building.

2.5.7 Air tight envelope

The building envelope has to be air tight for several reasons not only because of energy savings. Air tightness in the plane and air tight connections of the different parts of the envelope are in principle really cheap for new buildings, as has been shown in detail in the literature and actual building standards [13][Peper/Feist 1999], [7][DIN4108].

For old house renovation this may differ significantly. If the inside plaster and concrete ceilings (massive construction) are ok, there will be no extra costs. The numbers given in Table 2.5-3 include additional actions for parts of the envelope area for old building renovation if there are extra actions needed. The numbers are only rough estimates.

The detailed planning of cost effective air tight buildings is the primary task and genius of the planner and architect. The realization has to be supervised on the building site. Craftsmen and tradesmen have to be informed about the importance of an air tight construction, because this knowledge may not yet be obvious to everybody, see the additional information in the section about air tightness in this book.

2.5.8 Mechanical ventilation with heat recovery

A mechanical ventilation system substantially raises the air quality of living rooms. Besides the scientific proof, this is confirmed by numerous statements of satisfied users. The inhabitants do not need to open a window to get fresh air. The air flow which is necessary from the hygienic point of view (30 m³/h per person) is provided by small and highly efficient fans. The ventilation system operates day and night. The concentration of CO_2 in automatically ventilated rooms is by far lower than in standard residential buildings. The energy saving capacity of the heat recovery is very relevant for the function of a high performance building because the ventilation heat losses are reduced by about 70 % compared to window ventilation.

For the economic analysis only the energy

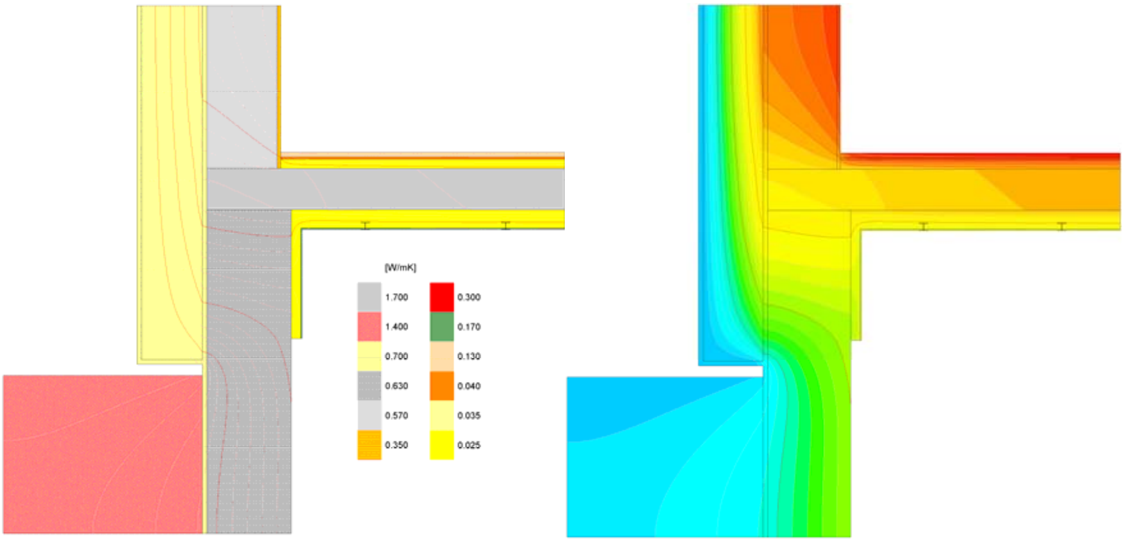


Figure 2.5-6
Wrapping of thermal bridge at edge to cellar to avoid low temperatures at inner surfaces: $U_{ceiling}$ = 0.177 W/(m²K). $U_{outside\ wall}$ = 0.122 W/(m²K) Ψ_a = 0.062 W/(mK) ϑ_{min} = 13.0 °C. [HMWi 2009]

See as well section 3.6 (thermal bridges) of this handbook.

savings are taken into account. Therefore the investment costs for this part are higher than the energy costs saved by the ventilation system itself. The assumptions of costs for the ventilation system are rough estimates for the system, air ducts and the workmanship of installation. On the other hand there are significantly less radiators needed in a building with a well thermally insulated outside envelope. This leads to cost savings which are able to finance part of the ventilation system as can be seen in Figure 2.5-4. and Table 2.5-3.

2.5.9 Extra costs for old house renovation compared to new construction

The numbers in Table 2.5-3 include the extra costs for actions needed for old house renovation. These are mainly costs for defusing the thermal bridges. The several cost numbers are added to the part of the envelope where they belong to (numbers and explanation in brackets). The thermal bridge at outside cellar wall has to be 'wrapped (+ 10 €/m² outside wall area), as well the inside cellar walls (+ 4 €/m² cellar ceiling area). At the roof edge additional parts need to be installed to give room for the insulation layer, see Figure 2.5-7 (+ 25 €/m² roof area). To install windows properly in the plane of insulation layer, sometimes the reveal of the old window has to be modified or removed (+ 40 €/m² window area).

As can be imagined easily all these cost numbers may vary significantly at special projects. Please note: all these numbers are based on data of massive constructions. Lightweight wooden constructions with wooden claddings outside have not yet been analysed.

2.5.10 Combination of actions for renovation to exclude 'anyway' costs

It is important to note that only those costs which are directly related to the energy savings, such as for example material for the insulation layer, the glue and the scaffold have to be taken into account when calculating numbers for the comparison with energy savings. Therefore, all costs for actions which are needed anyway when renovating a building may be excluded from the bill 'investment for energy saves'. These 'anyway' costs are for example costs for the outside rendering after the installation of the insulation layer, because the rendering would have been necessary as well every 20 years, even if no outside insulation would have been installed. The assumptions for anyway costs for all components (windows, ventilation, air tightness, etc.) were explained above, see Table 2.5-3.

Figure 2.5-7
If the upper ceiling is thermally insulated on top additional parts need to be installed at the roof edge to lift the roof tiles to give room for the insulation layer.

	old house	German building code (EnEV 2009)	Passive House refurbishment	anyway costs (to be excluded)	extra costs typical for old house renovation
roof (incl. wrapping of thermal bridges)	–	10 €/m²	33 €/m²	(1 €/m²)	19 €/m²
cellar ceiling (incl. wrapping of thermal bridges)		48 €/m²	71 €/m²	(43) €/m²	35 €/m²
outside wall		76 €/m²	96 €/m²	(43 €/m²)	0 €/m²
windows and doors (average value)	–	320 €/m² (conventional windows)	415 €/m²	(150 €/m²)	40 €/m² (modification of reveal
air tightness	–	–	3 €/m²	(2 €/m²)	2 €/m²
ventilation system (€/m² TFA)	–	30 €/m² (exhaust air ventilation system)	81 €/m² (vent. with heat recovery)	(30 €/m²)	3 €/m²

Table 2.5-3
Typical investment costs for energy saving actions. Specific numbers by area of component (wall, window etc.) or by living area (treated floor area, TFA). There are extra costs typical only for old house renovations which are denoted separately. The 'anyway costs' in the last coloumn are to be paid (e.g. for new outside rendering), but may be excluded from the budget for energy saving actions to evaluate the economic values, if actions are combined, see text.

This idea is most relevant for the economic balance of energy saving actions of old house renovation as well as for new construction. Only the extra costs can be paid by the energy savings during a reasonable time span. The anyway needed things must be excluded. This idea on the other hand leads directly to the **principle of combination** of actions to save energy (thermal insulation etc.) to those things which have to be done 'anyway' when renovating an old house.

Regarded vice versa: The **principle of combination** implies that actions for saving energy can then and only then be economically reasonable, if they are realized just in that moment when any component (outside wall, roof, or windows, etc.) have to be repaired or replaced anyway. Thus for the insulation layer only the costs for the layer, for a window, only the extra costs compared to an anyway needed window replacing the old one are taken into account.

This further implies that any component may only be replaced, if it has reached its end of lifetime (thermal insulation 50 years, window ≥ 30 years). Replacing newer components is not economically reasonable, because the energy savings cannot pay for the whole costs of the better component. There are some few exceptions from this rule: thermal insulation on top of the uppermost ceiling beyond the roof or thermal insulation of the cellar ceiling are rather cheap and therefore economically reasonable at any time without coupling to another action.

Conclusion: buildings are long lasting economic values and components of the building envelope have rather long lifetimes. So decisions of investment are **long term decisions which will bind the investor for many years.** Thus it is worth while to choose the better quality right now and to realize the 'future option', e.g. to realize 30 cm insulation layer thickness instead of only 15 cm. This means slightly higher investment costs now, but minimizes the risk of rising energy prices by far.

2.5.11 Glossary: Short explanation of additional benefit for the user

The investor and/or user have to know about what to buy and to choose. Therefore we must be able to explain this in short words:

A thermal insulation layer without thermal bridges inside covers the whole building envelope and provides for noticeably better thermal comfort, because the inner surface temperatures in winter rise significantly. In addition, the risk of humidity in the wall and hence the risk of growing mould at the inner surfaces can be ruled out definitely with U-values lower than 0.15 W/(m²K). So building damages originating from humidity need no longer be feared. As shown above, the energy saving potential is such high, that the total costs of a thermal insulation layer are lower than that of a standard wall or roof.

High performance windows with U-values less than 0.85 W/(m²K) provide as well for best thermal comfort. The minimum inner surface temperatures in winter nights can be kept higher than 17 °C without a heater beneath the window.

Mechanical ventilation with heat recovery substantially raises the air quality of living rooms. Besides the scientific proof, this is confirmed by numerous statements of satisfied users. The inhabitant does not need to open a window to get fresh air. The air change rate which is necessary from the hygienic point of view (30 m³/h per person) is provided by small and highly efficient vents. The ventilation system operates day and night. The concentration of CO_2 in automatically ventilated rooms is by far lower than in standard residential buildings. The energy saving capacity of the heat recovery is very relevant for the function of a high performance building because the ventilation heat losses are reduced by about 70 % compared to window ventilation. But for the users daily experience this function is hidden and therefore only inferior.

Advertisement is adequate information about products

All mentioned examples show, that the extra benefit of high performance building components can be explained with additional qualities which are more relevant for the users' daily experience. The energy saving capacity is relevant from the technical point of view and for the function of the building conception, but does not 'sell' for itself.

Nevertheless the additional benefit for the customer may balance the extra costs. This extra benefit has to be explained! This is hard work for products the customer cannot see afterwards such as a thermal insulation layer, which covers under the rendering of the wall. In some sense, this is a form of marketing for high quality products. It is just the job that other industries (automobile, computer etc) do since long time: advertisement is appropriate information about products.

2.5.12 Building costs – expenses for living

Construction of a building is an investment for the future. Our parent and grand parent generation said: everybody will build a house once in his life. Residential buildings in Europe have lifetimes of 50…100 years where some components have to be replaced or repaired after 20, 30 or 50 years as mentioned before. So this investment has to be planned carefully not only from the financial point of view. This is true even today, as many people change their living place for several times during their life.

The scientific approach to high performance buildings during the last two decades showed up not at least in the framework of IEA Task 37, that two aspects in building concepts have to be revisited thoroughly. These are the thermal performance of the building envelope and the air quality inside the building as explained in detail elsewhere in this book.

Both aspects up to now have been mainly discussed theoretically, so non experts do rarely understand what is going on or what is important. The consequence is that customers are on the one hand recommended to invest more money for better air quality (ventilation system) or better thermal comfort (more thermal insulation) but on the other hand he or she does not really know very much about the quality of those things. Thus people have to pay extra for things they do not know enough about and hence they do not really want to have it.

The financial aspect: The discussion of total costs in this chapter has shown, that the extra costs for high performance components are moderate, zero or negative, if – and only then – if all costs, the running costs resulting from energy losses, too, are taken into account. But people who buy an apartment or a single family home normally have a limited budget and therefore have their eyes mainly on the investment costs which they have to pay right NOW. Anything extra, which is not fashionable or its use cannot be explained with obvious striking arguments will be skipped if possible, because of the extra expenses. So, marble bathroom tiles or golden water taps are normally easier to sell than a thermal insulation layer or a mechanical ventilation system.

Additional expenses to fulfil an additional benefit for the user

Turning this fact vice versa means that an additional benefit of a building component which is obvious for the client, people are mostly willing to pay for [16][Kaufmann/Feist 2003]. This is not just a marketing problem. This is more than marketing: This is a task of information which has to be mentioned just here in the context of building costs. This is a general task of dissemination of information which we must fulfil the next few years. This chapter hopefully helps a little for that.

People will live in their buildings for many years. When buying a building or do a renovation of an older one, they need reliable information about the qualities of the components used for that. In the moment when the decision has to be done there is a chance to explain to the 'investor' – the family or the housing company – the qualities of high performance thermal building components to show them what chances and extra benefit will result from choosing just these for their renovation instead of standard components.

With the more and more spreading information e.g. about mechanical ventilation systems and thermal insulation layers these components will perhaps become more fashionable within the next decade...

2.5.13 Outlook: positive financial risk evaluation for high performance houses

Is it necessary that expenses for high thermal performance components compete with the other equipment of the building? The budget for building a house is limited because the customer must be able to afford the annual payments for the investment costs in total. For this reason the maximum financial charge that is allowed to a private person or as well to a housing company is limited. The limit is oriented at the available capital.

In this context the financial risk examination has to be analyzed and evaluated. The running costs during lifetime of the building have to be taken into account and have to be added to the annual capital costs as shown in the cost calculations in this chapter.

Doing so, it turns out, that a high thermal performance building renovation has by far a lower risk of increasing running costs because the dependence on fossil fuel importation and the related energy prices is much lower than for a standard building. The total risk of a building investment is lower for highly energy efficient buildings. Therefore, risk capital is not needed for the additional costs for economically feasible energy efficiency investment which can be financed by additional mortgage credits. This fact has to be taken into account when designing financial plans for the customer planning a renovation project or buying a new home. For those who choose the better components described above the financing volume limit may be increased. For the same reason it should be interesting for a bank to get such projects because the default risk is lower.

Up to now investment costs and running costs for energy consumption are accounted to separate cost centres. Especially for rented flats this is in contradiction to the ecological and economical needs. The owner of the house has to do an investment for the refurbishment; the tenant has the advantage of the lower energy costs afterwards. So the owner will do that investment only if he is funded e.g. by the government as is the case today in Germany (KfW funding by credits with lowered rate of interest) or if the housing company can increase the rent for the flat.

These questions are very delicate because they affect the social balance of rental homes. But it is worth to discuss new models of a "warm rent" which may be lower than the total monthly expenses for a tenant today.

For the people buying or renovating their own homes these questions are already now a realistic option which should be caught. The advice given by the architect and planer who manage the construction costs and the consultancy by the banks who manage the money to pay the costs must lead to 'sustainable' solutions which are financially affordable for all partners involved.

2.5.14 Summary: we are on a good way

The development of high thermal performance buildings is on a good way. The components for these constructions are available and the costs for them are decreasing because mass production seems reachable.

National economic arguments have to be taken into account and will become more important in the future: high thermal performance housing renovation means locally added value for the national economy instead of globally spent expenses for mineral oil or gas. This locally added value provides for an extra benefit for the customer (higher thermal comfort) for which he is willing to pay moderate extra expenses.

So the development of high thermal performance buildings turns out to be a 'multi win' story for all actors involved:

- The customer who gets a comfortable sustainable and hence affordable renovated or new built home.

- The people creating or renovating these buildings and the related products: Architects, Craftsmen, Industry. They produce and earn the locally added value.
- The national economies that profit from the positive economical climate.
- Last but not least our 'environment', the globe – home for us and for our children.

Last statement for discussion: The interest rate for loans is since years much more stable (≤ 5 %) than the price for energy, this will hopefully be a reliable fact for the future.

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3 Building Envelope

3.1 Typology, Problems and Solutions

Berthold Kaufmann

The building envelope is the 'shell' of our homes. Thus it has to prevent us from outside weather mainly rainwater and hot or cold temperatures.

The main parts of the building envelope are the opaque components such as walls, roof and ground plate (basement) on the one hand and transparent components such as windows and doors.

For all building envelope components the main quality with respect to energy losses are the U-values.

All **opaque building** components should have maximum U-values of about 0.15 W/m²K or even better to achieve a real good resistance against heat losses.

The outside walls of old buildings may be thermally insulated in a very similar way as walls of new buildings: polystyrene blocks glued to the wall and added outside rendering give a very cost effective insulation system. But as well wooden beams (6 cm x 25 cm) fixed to the wall with a distance of 60...70 cm as with lightweight wooden constructions is possible as well.

Thermal insulation in the roof or above the highest ceiling is a rather cost effective component of a building. On-roof insulation panels out of high density mineral wool or polystyrene and polyurethane blocks are available since years. Doubling the rafters of the roof is as well possible and leads in most cases to a cost effective and stable construction.

The basement of an old building can mostly not be thermally insulated under the slab. But the ceiling of the cellar under the ground floor apartment can be insulated, if the room-height of the cellar and/or the apartment is high enough. So U-values of maximum 0.2 W/m²K are realistic.

Windows are crucial parts of the building envelope. High average surface temperatures on the inner surfaces of glass and frame are the precondition for good thermal comfort beneath the window. Therefore the U-values (U_w as an average over the entire window) must be about 0.8 W/m²K or lower for moderate cool climate regions like middle of Europe. Such low U-value can be achieved by three pane glazing with noble gas filling and IR-coating on the one hand. In addition the experience shows clearly that well insulated window frames with U-value $U_f \leq 0.75$ W/m²K are a precondition for that, too. Meanwhile such frames are available in many different shapes and all materials (wood, PVC), even frames with a construction depth and visible width of about 110 mm are available. Such 'slim profiles', which architects like, are possible.

For colder climatic regions (Northern Europe) the requirements are harder, because of lower outside temperatures and lower solar gains, in warmer climates (e.g. Mediterranean) higher U-values may be suitable. This has to be checked carefully for each building location.

Thermal bridges (see the next section) are a very important issue when planning a thermally optimized building envelope: having very low component-U-values badly designed junctions with heavy thermal bridge effects can enlarge the heat energy demand of the renovated building significantly.

Besides the thermal qualities of the envelope components the **shape of the overall building** is crucial for the later thermal performance of the building. Therefore it is highly recommended to have 'compact buildings': extensions at the side or on the roof like dormers should be avoided or optimized during the planning of renovation. This helps in addition to reduce building costs.

3.2 Thermal bridges

Johann Reiss

3.2.1 Introduction

Providing thermal insulation to building envelope surfaces requires special attention to be paid to the phenomenon of thermal bridging. Particularly in highly insulated buildings, heat bridges have a great impact on the energy consumption. Permanently increasing the thickness of insulating layers will remain ineffective, unless the impact of thermal bridging is not going to be reduced in parallel. It is true that thermal bridges cannot be entirely avoided; they may be significantly reduced, however, if the application of thermal insulation systems to the building envelope is carefully planned and executed. Thermal bridges are defined as those areas in the thermal envelope of a building, which are distinguished by the occurrence of increased heat flows and lower inner surface temperatures during the heating period (compared to an undisturbed building component). These occurrences are due to material changes in the component level and/or the building component's geometry. A distinction is drawn between material-induced and geometry-induced thermal bridges. Quite often, both influences have also been found to interact. Lower temperatures of the interior surfaces may imply mould growth. The substantial benefit of insulating the external surfaces of a building's envelope is actually due to the fact that the temperatures of the internal surfaces will be raised in the area of the thermal bridges. In this way, the impact of thermal bridges will be reduced. If internal insulation has been applied, this effect is not encountered in all cases (see Figure 3.2-1).

3.2.2 Impact of thermal bridging

Risk of mould growth

Thermal bridges cause a drop in temperature at the interior surface of the building component. As a consequence, such surfaces may be affected by mould growth.

At a given indoor air temperature of 20 °C and a relative indoor air humidity of 50 % there will be surface condensation at a component with a surface temperature $\theta_{si} \leq 9.3$ °C. In this case, the relative humidity of the component surface is 100 %. As some investigations [21] have proven, however, several mould species are already able to grow when the relative humidity at the component surface is ≥ 80 %. With regard to the surface temperature this means: the building component's surface temperature θ_{si} must be ≥ 12.6 °C to surely avoid mould growth. The relative humidity resultant at the building component surface is determined using the following equation:

$$\varphi_{si} = \left[\frac{109.8+\theta_i}{109.8+\theta_{si}} \right]^{8.01} 0.5$$

φ_{si}	relative humidity at component surface
θ_i	indoor air temperature
θ_{si}	surface temperature of building component

This relationship is graphically represented in Figure 3.2-2.

To assess possible risks of mould formation, the surface temperature needs to be

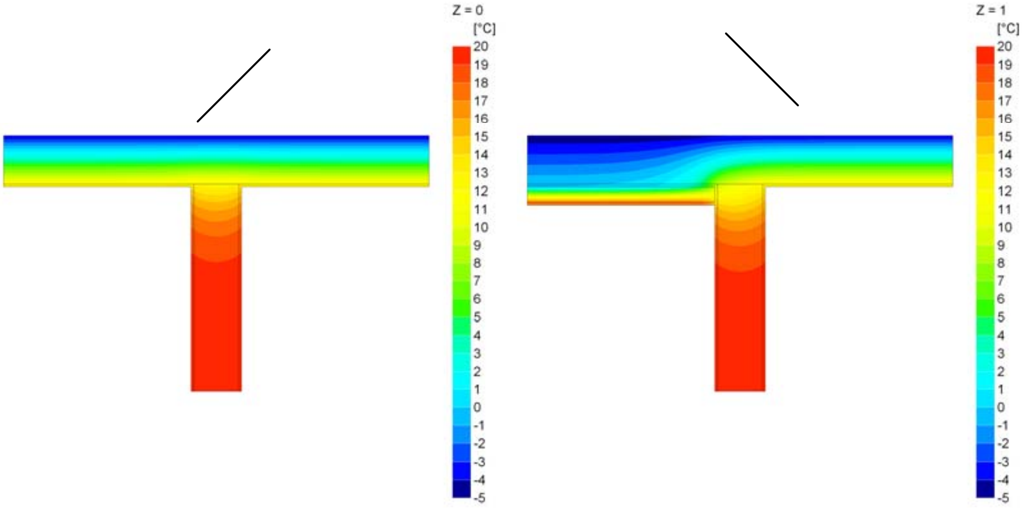

Figure 3.2-1
Compilation of thermal bridging catalogues

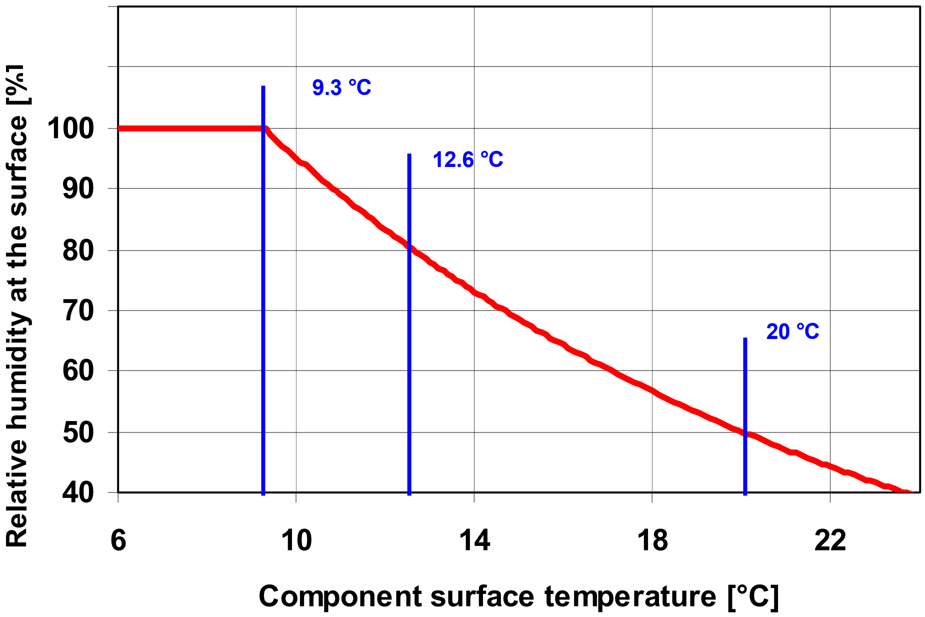

Figure 3.2-2
Relative humidity at the surface of the building component, given for different component surface temperatures (indoor air humidity 50 %, indoor air temperature 20 °C)

calculated. The dimensionless surface temperature was introduced in order to become independent of fixed boundary conditions for temperature [22].

$$f_{Rsi} = \frac{\theta_{si} - \theta_e}{\theta_i - \theta_e}$$

f_{Rsi}	temperature factor
θ_{si}	indoor air temperature
θ_e	outdoor air temperature

German regulations [22] stipulate that fRsi ≥ 0.70 must be ensured for both new constructions and for renovation measures. Assuming an outdoor air temperature θ_e of -5 °C and an indoor air temperature θ_i of 20 °C along with a temperature factor fRsi of 0.70, a surface temperature of 12.6 °C will result.

Increased heat losses due to thermal bridging

Besides the risk of mould growth, also increased heat losses are encountered in the area of thermal bridges. Since practical experience has shown that it is very complicated and time-consuming to determine the heat flow by measurements, it is determined by calculation. Though infrared thermographs allows localizing thermal bridges from the outside of a building as well as from the inside, it is not possible to quantify the amount of the heat flow by using this technique.

According to reference [23], the transmission heat losses of the heat-exchanging building skin per K temperature difference are equal to

$$H_T = \sum_i U_i \cdot A_i + \sum_j \Psi_j \cdot l_j + \sum_k \chi_k$$

U	Thermal transmittance of the building component
A	Surface area of building component
l	Length of thermal bridge
Ψ	Linear loss coefficient of the thermal bridge
χ	Point loss coefficient of the thermal bridge

The increased linear heat losses are considered by factor Ψ, while the point heat losses are considered by factor χ.

These are determined in the following manner:

$$\psi = L^{2D} - \sum_j U_j \cdot l_j$$

L^{2D}	thermal conductance, determined from 2-dimensional calculations.

$$\chi = L^{3D} - \sum_j L_j \, {}^{2D} l_j - \sum_i U_i \cdot A_i$$

L^{3D}	thermal conductance, determined from 3-dimensional calculations.

3.2.3 Assessment of thermal bridges

The Fourier equation is used to describe the heat flow through a three-dimensional building component:

$$\frac{\partial\theta}{\partial x^2}+\frac{\partial\theta}{\partial y^2}+\frac{\partial\theta}{\partial z^2}=0$$

This equation cannot be solved by a simple manual calculation but requires the use of a computing programme, instead.

Computing routines

In Table 3.2-1 (following [24]) different computing programmes have been compiled, some of which are available free of charge, most programmes are however commercial software. Apart from the costly 3D-programmes, there are also 2D-programmes available. The programmes are only suited for the calculation of heat transfer. It is not possible to calculate the air and moisture transfer using these programmes. As a rule, thermal bridges are calculated for steady-state boundary conditions (Steady-state, SS). In some cases, however, dynamic calculations are also required (particularly in those cases where building components are limited by the ground). The table gives a survey of those programmes that enable us to compute such applications. Some programmes not only allow to compute rectangular shapes (RECT) but also to calculate any arbitrary shapes (FF). The calculation of heat losses through thermal bridges is decisively influenced by the Ψ-value, which is directly indicated by some programmes only.

The application of computing programmes requires substantial experience regarding the appropriate and necessary discretisation of the building component. Also, particular attention must be attributed to determining the temperature boundary conditions when three and more areas of different temperatures are being observed. Relevant issues that must be considered when applying a calculation routine have been compiled in DIN EN ISO 10211 [25].

Catalogues of thermal bridges

Computing routines are not absolutely necessary to determine thermal bridges. It is also possible to assess thermal bridges by using inventories in which thermal bridges are listed. Thermal bridge loss coefficients Ψ and temperature factors f_{Rsi} are specified for several types of constructions. These inventories have a disadvantage, however: in most cases, there are no direct representations showing the required constructions in detail. Nevertheless, experienced users who have a sufficient expert knowledge of the matter can still make good use of the thermal bridging catalogue, simply by selecting a construction with a poorer thermal and energy performance. In this way, the user will find a solution to this task that will definitely keep him on the safe side. The specified

Table 3.2-1
Compilation of thermal bridging catalogues

Title	Language	Types of buildings	Flexibility	Used in
EN ISO 14683: Thermal bridges in building construction [25]	English	Residential	No	Europe
Catalogue of thermal bridges [41]	German	Residential	Yes	Switzerland
KOBRA v3.0w [33]	French, Dutch	All types	Yes	Belgiu
U-values 2003 [42]	Danish	All types	No	Denmark
Danish Standard 418. Calculation of heat loss from buildings [43]	Danish	All types	No	Denmark
Thermal bridge atlas for wooden construction [45]	German	Wooden construction	Yes	Germany
Thermal bridge atlas for brick construction [46]	German	Brick construction	Yes	Germany
Catalogue of thermal bridges for renovation and retrofitting measures [47]	German	All types	Yes	Germany
Building Research Design Sheet 471.017. Thermal bridges [48]	Eglish/ Norwegian			Norway
Limiting Thermal Bridging and Air Infiltration [49]	English	All types	Yes	Ireland
Supplement #2 of DIN 4108 [50]	German	All types	No	Grmany
New catalogue of thermal bridges [51]	German	All types	No	Germany

constructions were calculated using a computing routine. Some inventories actually allow varying the geometry, the thickness of the insulating layer, and the thermal conductivity. On the other hand, the advantage of these inventories is cost-related: it is clearly less expensive to buy such a catalogue than to purchase a computing programme. Moreover, only a relatively short training period is required. Another disadvantage compared to computing routines is the poorer degree of accuracy. Anyhow, catalogues are a good choice when doing a quick check of the building-component connection or in preliminary planning. In reference [24] a number of thermal bridging catalogues have been compiled. Table 3-2 contains just some of these.

In Annex A of EN ISO 14683 [41] rough guide values are indicated for typical thermal bridges, which are commonly encountered in residential buildings. These are two-dimensional thermal bridges. The values have been rounded to 0.05 W/(mK). The thermal bridging catalogue edited by Schweizer Bundesamt fuer Energie (Swiss Federal Office of Energy) [42] contains a great number of constructions. On average, the U-values of the building components vary from 0.40 W/(m²K) to 0.15 W/(m²K). In 2008, a supplementary catalogue for Minergie-buildings was published. This document contains constructions up to a U-Value of 0.10 W/(m²K). The catalogues published by Hauser [45],[46] and [47] have a long tradition, which is why they do not cover constructions with high-performance thermal insulation. The catalogue [47] was specially prepared for renovation projects of residential buildings. However, the principal intention when compiling this catalogue was the prevention of mould growth. In general, the varied thicknesses of insulating layers do not go beyond a thickness of 120 mm. In Germany, a value ΔU of 0.10 W/(m²K) must be added to the average U-value of the building skin if the thermal bridges are not considered when calculating the transmission losses HT of a heated building. On the other hand, if all thermal bridges are constructed in accordance with the specifications given in [50](or even better), the ΔU-value will be reduced to 0.05 W/(m²K). If an actual construction that needs to be assessed deviates from the reference construction selected from [49], it is possible to conduct a comparative proof. In [50] mainly such constructions are considered and assessed, which are listed in [49]. In [52], surface temperatures θsi are represented, just like Ψ- and χ-values for three-dimensional construction details in solid constructions. [53] is an electronic catalogue of thermal bridges.

For new constructions, though, and for buildings that are designed to undergo retrofitting to achieve optimum energy performance, these global values of 0.10 W/m²K and 0.05 W/m²K are way too high. The total sum of the additional transmission heat losses that are caused by thermal bridging can be reduced to zero. This reduction, however, requires the precise analysis and assessment of each individual thermal bridge. As a rule, it will not be possible to reduce each and every ψ- and χ-value to zero. However, since usually there are at least some thermal bridges in each building that are characterized by negative heat loss coefficients (like vertical edges of external walls, for instance), the following sum can be formulated in such a way that it will result to zero or even become negative:

$$\sum_k \Psi_k \cdot l_k + \sum_j \chi_j$$

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3.3 Air tightness

3.3.1 General requirements and basic explanations

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The envelope of a building should be as airtight as possible - this is true for passive houses as well as for highly efficient renovations. It is the only means to avoid damage caused by condensation of moist, warm air from the rooms penetrating the construction. Such damage not only occurs in cold climates; in hot and humid climates the problem can occur from airflows from the outside to the inside. The cause is the same in both cases: a leaky building envelope.

Drafts in living spaces are frequently reason for complaints by occupants in conventional buildings: Therefore an airtight construction is essential to fulfil thermal comfort expectations [cf. EN ISO 7730]. Most building codes, worldwide, require airtight building envelopes and this is a reasonable and useful requirement.

Air tightness should not be mistaken for insulation. Both qualities are essential characteristics of a high quality building envelope, but in most cases both have to be achieved independently: A well insulated construction is not necessarily airtight, too. Air can easily pass through insulation made from coconut, mineral or glass wool. These materials have excellent insulation properties, but are not airtight.

On the other hand an airtight construction is not necessarily well insulated: e.g. a single aluminium foil can achieve excellent air tightness, but has no relevant insulation property. Air tightness is an important, but not the most important requirement for energy efficient buildings.

Furthermore, achieving air tightness should not be mistaken with the function of a "vapour barrier". The latter is a diffusion tight layer: An oiled paper e.g. is airtight, but it allows vapour to pass through. Conventional room plastering (gypsum or lime plaster, cement plaster or reinforced clay plaster) is sufficiently airtight, but allows vapour diffusion. Of course both functions can be combined e.g. using PE-foil as it is frequently done in wooden construction.

Infiltration can not guarantee good indoor air quality. Houses built in Germany after 1985, for example, are so airtight that infiltration alone is inadequate to assure acceptable indoor air quality. Yet, these houses are still at risk regarding moisture damage to the construction from moist room air exfiltration.

To rate the air tightness property of a building a pressurisation test is performed according to [EN 13829]. The ratio of the assessed airflow through the leakiness of the building envelope at 50 Pa pressure difference and the inner air volume of the building is calculated. The number obtained is abbreviated n_{50} and is a practicable means to describe the building's air tightness performance: The lower n_{50} the better the air tightness. For Passive Houses the limit is at $n_{50} \leq 0{,}6\ h^{-1}$.

Most existing buildings must be considered as "leaky". Their n_{50}-air leakage varies between 4 and 10 h^{-1}. The consequences are draft-discomfort and moisture damage to the construction. The construction is too leaky to avoid exfiltration caused damages - but too tight for sufficient infiltration to maintain good room air quality.

In Passive Houses and highly efficient renovations with Passive House components far better n_{50} leakage rates are regularly achieved with reasonable effort. In practice values between 0.2 und 0.6 h^{-1} have been measured in passive houses (at a mean of 0,37 h^{-1} in 200 surveyed buildings).

Air tightness is not a question whether a construction is massive or light weight. Built passive houses using masonry, timber, prefabricated, lost form with concrete and steel bearing structure have achieved this superior level of air tightness. Careful design and accurate workmanship are the prerequisites to success. Construction details needed to achieve tightness are available for all important joint and envelope penetration situations.

Air tightness should be recognised as a planning task of its own. A building shell can be air tight only if it consists of *one* uniform, intact, airtight enclosure wrapped around the whole volume. In a first step, for each element of the envelope, the course of the airtight layer must be specified (e.g. the interior OSB cladding in a roof construction). In a second step airtight joints of elements are planned.

A key principle is maintaining "an undisturbed, airtight envelope", which can be recognised by the "rule of the red line".

In drawings of building sections or floor plans the airtight layer can be drawn with a (red) pen without interruption in any scale.

As indicated above good air tightness is essential in highly efficient buildings. This is true not only for new construction of e.g. Passive Houses but also for advanced energy efficient renovation. The main aim is to ensure a draft free interior and simultaneously avoid exfiltration of humid room air and consecutive moisture related damages to the construction. Moreover only an airtight building shell allows for highly efficient ventilation with heat recovery.

Components and technologies for airtight construction are widely available for massive as well as for framed/light construction methods.

In massive construction usually the interior plastering serves as the airtight layer. Consequently the plastering needs to be applied on the whole area of the walls regardless of visibility. It should therefore be applied before screed and any pipes/installations are placed. Electrical installations need to be mounted airtight which can easily be achieved by placing the in-wall sockets and cables in plenty of plaster. Airtight strips of windows and doors are bonded on a layer of pre-plastering in the soffit and finally covered with the visible plastering. Fleece coatings secure good adherence of the plaster. Sometimes it is required to use special primers to allow for a secure bonding of the airtight strips.

In wooden construction a layer of OSB is often used as an airtight layer. Joints are sealed with special airtight adhesive tape. Often a separate installation layer is added on the interior to ease (electrical) installation without interfering with the airtight layer. Any penetrations of cables or pipes are easiest achieved in reliable airtight quality using adhesive EPDM collars that are available in all sizes from single cable diameter to drain pipe.

The guiding ideas of airtight construction are:

- air tightness of a building is a planning task
- there must be *just one* uninterrupted airtight layer wrapped all around the building's volume
- all details and joints / penetrations must be checked for permanent air tightness
- the course of the airtight layer and specifications of materials / technologies to be used must be included in the drawings

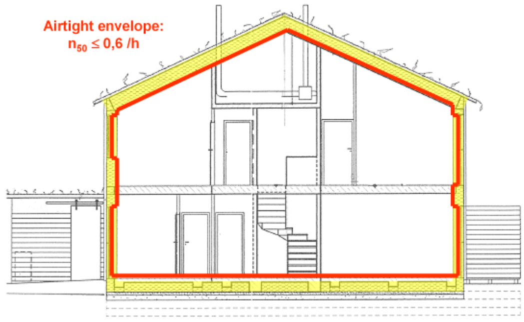

Figure 3.3-1
The position of the airtight layer has to be planned carefully to avoid complications on the building site.

This is true as well for old house renovation where problems with the existing structure may complicate things.

In renovation scenarios with exterior insulation it is always important to check for possible airtight strategies at an early stage of the process. In many cases it is possible and by far preferable to overhaul and complete the plastering. To survey the leakages of the building a first pressurisation test should be performed in the untouched building. The following works can then be conducted a lot more precisely.

Yet sometimes difficulties are encountered. E.g. if there are wood beam ceilings in massive buildings the spaces between beams are usually not plastered. To ex post add plaster there the flooring needs to be removed which is costly and still leaves the problem of connecting the wooden beams to the plaster. Or media ducts full of piping are to be kept and plastering cannot be performed with reasonable effort. In such cases it is also possible to add the airtight layer on the exterior. It is even an option to use the adhesive for the exterior insulation as an airtight layer if it is applied seamlessly on the whole surface. (The suitability of the product used should be checked thoroughly.) Moreover all connection details at windows, roof, and base/cellar need to be well designed. For more details see [55][AkkP 24].

3.3.2 Pressurisation test

To quantify leakages in a building shell the pressure differential technique according to [EN 13829] is widely used. Also known as "Blower Door Test" the method offers good results (total measuring error < ±10%) at reasonable cost. Additionally it offers a simple way to trace and locate relevant leakages in low pressure mode.

Since many leakages can be traced and repaired with little effort if only the airtight layer is well accessible the best time for performing the test is just when the airtight layer is finished but not yet covered with any additional elements.

To perform the test a building needs to be prepared: Water seals in the pipe work need to be filled with water, ventilation is shut down and fresh-air and exhaust-air ducts are sealed.

- Designed openings in the building envelope as needed e.g. for ventilation ducts are sealed during the measurement.
- Any other parts of the building shell are left 'as is' in the normal condition.

After that preparation a fan combined with a measuring orifice is installed mostly by covering a door or window opening with a piece of impermeable cloth within which the fan is mounted. Dependant on the operating direction of the fan the house's volume is pressurised or depressurised.

Usually at the beginning of a test remaining leakages are searched by applying a constant depressurisation of 50 Pa. In that condition air infiltrating through imperfections of the airtight layer can be found by simply feeling with fingertips, by using an anemometer or even an infrared camera. If craftsmen are present any faults discovered can be fixed immediately.

After leakage search is completed the original measurement starts. At a number of differential pressure values (≥5) usually between ±20 Pa and ±80 Pa the respective flow rates are collected. This can be done by manually reading pressure gauges or by using automated electronic equipment. Since electronic equipment allows collecting hundreds of values for each point a statistical survey can enhance accuracy significantly.

From the data collected a formula that describes the dependence of flow and pressure is derived for positive as well as for negative pressure. In further analysis the flow rates normalised to ±50 Pa differential pressure are calculated. The mean flow rate is then divided by the building's interior air volume to determine the fraction n_{50}.

n_{50} = leakage airflow @ 50 Pa/(interior air volume of the building)

Since n_{50} values are a calculated as a fraction of airflow [m^3h^{-1}] / air volume [m^3] the dimension is h^{-1}.

For advanced housing renovation as well as for other highly efficient buildings that are designed to be equipped with a ventilation system with heat recovery n_{50} must not exceed 0,6 h^{-1}. This is due to four main reasons. A larger quantity of leakage brings the risk of *draft and thermal discomfort* together with likely *damage to the construction* by moisture from exfiltrating air. Moreover exfiltrating warm air means additional *heat loss* and consecutively higher annual space heat demand and *increased heating loads*. In buildings with fresh air heating this may threaten the heatability of the house. Finally the *ventilation system with heat recovery* can only be operated efficiently if really all airflow into and out the building is achieved via the ventilation system.

In realised projects such as Jean-Paul Platz 4 (Nuremberg, Germany), Hoheloogstraße 1+3 (Ludwigshafen, Germany) and Tevesstraße 36-54 (Frankfurt/M, Germany) a mean n_{50} value of 0,47 h^{-1} has been measured (13 buildings tested, standard deviation 0,11).

Thus it can be regarded proven that comparable values as in new construction of Passive Houses can be achieved with reasonable effort for the later inhabitant's benefit: Best thermal comfort, fresh air and healthy environment can be supplied at very low energy demand.

3.3.3 Strategies and best practice examples

Andreas Gütermann
Berthold Kaufmann

Achieving air tightness is an essential element in any insulation strategy. Following is a short chapter on strategies and some best practice examples. The subject of air tightness raises several questions:

1. Highly energy efficient buildings should be air-tight, but how to achieve that practically? This is especially difficult to achieve but equally important by building renovation.

2. Air tightness does not necessarily mean vapour tight. If the material which forms the airtight layer is vapour permeable instead of being a vapour barrier, moisture can penetrate the membrane even it is airtight. This allows for drying e.g. during summer if moisture had entered the construction during a cold period.

Please note: vapour diffusion can transport (dry out) only very small quantities of water compared to those water quantities which may enter the construction by airflow of humid warm air from inside the building through a leakage of the air tightness layer. Therefore, please care on long lasting good air tightness:

3. Moisture problems can occur if the air tight layer has a leakage or a leaky joint. Joints may be airtight upon completion of the construction but may degrade and then fail later if the materials are not durable. So if leakages open later-on, moist warm air could penetrate the barrier and condensation could occur in colder layers of the construction. This would then result in damage to the construction and then would require expensive repairs.

So it is highly recommended to take care on long lasting airtight joints: taping and gluing of foils at joints must be performed very carefully. All materials used for taping and gluing need to be of proven quality. This means especially only to use material combinations (e.g. foil/glue) which are proven by the manufacturer to fit together.

One example: standard foil is powdered to avoid the layers on the transportation role not to stick together after transport. This foil may not be used with many tapes/glues, because the connection will degrade very soon. So check carefully the manufacturer’s specification otherwise the manufacturers guaranty will fail.

4. The air tight barrier is preferably realized on the room side of the insulated wall, while the wind tight barrier is best on the outside, in heating dominated (cold) climate regions. In hot and humid climates the air tight barrier should be on the outside to prevent humid outside air from penetrating into the insulation layer.

Short hint about humidity and diffusion

As a general building physics rule for cold climate regions the vapour resistance of layers of any construction must diminish from the warm side to the cold side: "inside tight (airtight and vapour tight!) outside open (for diffusion)".

So in most cases it is a good idea to combine the quality of air tightness and relatively high diffusion tightness of the inside layer. By the same rule the exterior rendering should therefore not be a barrier for moister diffusion. Please note: Different types of plaster have different moisture resistances and should be chosen appropriately.

Please note as mentioned above: air leakages lead to much higher moisture transport into a construction than diffusion does.

A weather barrier, on the outside is important to prevent wind from driving cold air into and around insulation bats or panels. So the wind tight plane is located outside whereas the airtight layer is recommended to be located at the inside of the construction.

Where to place the airtight layer?

When renovating existing constructions it has to be decided carefully where to place especially the airtight layer.

For example (see below, option 2 of the section 'best practice') it might be useful for a massive wall to have the airtight layer in the plane of the old rendering outside the existing masonry wall (cheap plastering) but inside the new insulation layer out of polystyrene blocks. The airtight layer of the renovation project 'Jean-Paul-Platz' in Nuremberg has been realized like that [57][Jean-Paul-Platz].

Exterior Walls

To seal an even plane is relatively easy. In older buildings brick walls are usually made with mortar and plastered on both sides. Neither the brick with their pores nor the mortar joints are airtight, never!

Plastering on inside of the masonry wall is reasonably air tight, if there are no hair-line cracks. That is mostly true for inside plaster but exterior stucco exposed to the elements poses more of a problem.

Rule of thumb: If every part of the building is as air tight as a plastered wall the building is sufficiently airtight.

An old outside rendering can be made airtight by:

- Thoroughly filling all cracks
- Full-surface glue exterior insulation instead of spot gluing so that the glue serves like a glue-plaster barrier.
- Additional pinning of the insulation blocks may be helpful and is needed, if the old outside rendering is not sticky enough to the brick wall. If not needed you may save much money for and save heavy thermal bridge effects of the pins, but this has to be checked carefully: glue and tear with one block for test. These tests are often done by the manufacturers who have to give the guarantee that the mounting of the insulation is durable.
- Rendering on the outside of the insulation creates a weather (wind) shield, or:
- Add a wind barrier (foil) on the outside of the insulation layer and then use an outer sheathing with a ventilated gap.

- When using rigid materials (e.g. blocks of polystyrene or mineral wool) for the insulation layer, gaps between blocks should be avoided absolutely. Otherwise cold air may flow behind and between the blocks leading to severe thermal bridge effects. If gaps are present accidentally they must be filled by foam or flexible mineral wool.

Best practice: there are several possibilities for the position of the airtight layer

As shown in Figure 3.3-2 the air tightness layer may be realized in three different manners and planes respectively:

- The interior plaster improved to remove imperfections and to be connected to ceiling and floor.
- The old exterior stucco, improved to be fully airtight, behind the new insulation.
- The new exterior rendering at the outside of the insulation layer.

The first two possibilities are the most suitable to reach the best results. The last one is normally not used for air tightness.

It must be stated clearly: the best results are achieved, if just only one airtight layer is designed and realized all around the building envelope.

Some times this principle cannot be realized at every junction. For example the connection of cellar ceiling to the outside wall may be critical if the wall of the cellar is too porous. In those situations it helps to have the both plastered surfaces outside and inside of the cellar wall as far as possible down as shown in Figure 3.3-2.

The option 1, the improved inside plastering, leads whenever possible to the best results.

If a building is occupied during renovation, or what is more, when there are wooden beams present in the ceilings, it is much better to realize option 2: When using the old but improved stucco under the new insulation layer, all wooden beams are inside the airtight envelope and all the other imperfections of the inside wall surfaces with respect to air tightness are no more relevant.

See for example Figure 3.3-3: often there are gaps behind electrical plugs or behind the mopboard all around the room edges which cannot be sealed if not all the flooring would be removed. All this problems are solved if the old but improved rendering layer behind the new insulation blocks is made airtight [57][Jean-Paul-Platz].

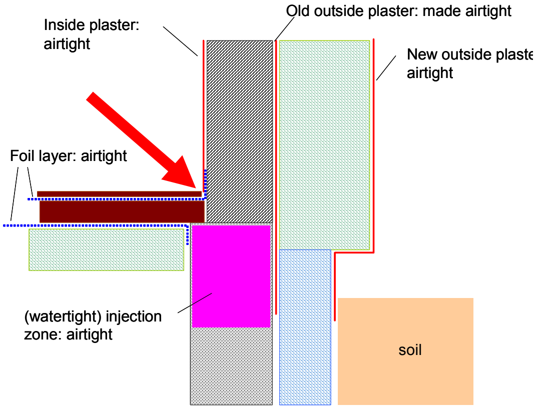

Figure 3.3-2
There are several possibilities for the position of the airtight layer.
But you must decide once during planning and then stick to the decision.

Figure 3.3-3
Inside plaster is not connected to the floor, and the electric plug, covering many air leakage paths.

Joints between building components

Another key issue is the airtight sealing of joints and designed openings through the exterior envelope, such as:

- Joints around window frames
- Joints from wall to the ground floor or basement ceiling
- Electric wiring and other wall penetrations
- Joints between the walls and roof

These are now shortly reviewed.

Joints to the window frame

Windows should be located in or adjoining to the insulation layer. In any case it is important that the window frame is properly connected to the air tightness layer of the wall.

When using option one (see above and Figure 3.3-4), the airtight connection goes to the new or improved inside plastering. Several airtight connections are possible: taping or grids which are covered by plaster in reveal etc. But please, never use foam (the open cell structure will never be airtight!) and never use silicon (will crack very soon!) for airtight connections.

When using option 2 the connection goes to the old but improved rendering on the outside of the masonry wall. This is done by taping the windows to that plaster skin. This may be cheap, because no sophisticated finish is needed.

Please note: when using tapes for airtight connections the surfaces especially of masonry walls have to be prepared carefully, so that the connection of tape to wall remains airtight for a long time. Otherwise the surfaces to be glued to are probably dirty, dusty, rough and possibly wet so glue will not bond! Surfaces to be taped or otherwise glued to must be dry and clean and reasonably smooth. On porous surfaces (wood, brick, concrete or plaster) a primer must be applied for best and long lasting adherence.

Joints between the ground floor and basement ceiling

The situation shown in Figure 3.3-3 does not seem "critical", but it is! The wall itself may be airtight, as long as the plaster has no cracks, but the floor (behind the mopboard in the Figure) and the supporting framing may have leakage paths. The solution depends on the floor construction, as follows:

If wooden parquet is over a full concrete slab, there is no problem. But please check, if the inside plaster is connected all down the concrete floor or ceiling respectively.

If the flooring is over a subflooring supported by wooden joists penetrating the exterior foundation walls, there is a problem. This may only be solved by option 2: air tight layer outside the masonry wall in the plane of the old plastering, see above [57][Jean-Paul-Platz].

If there is a poured levelling grout over the subfloor, then only the joint to the wall is critical.

If there is no levelling grout the following solutions may work:

1. Remove the old parquet and pour a cement layer. Pay attention to the strength of the beams, which might have to be reinforced.

2. Apply an airtight foil membrane and carefully seal it too the walls. This solution can also be applied on top of the old parquet before installing the new floor.

3. Most likely the basement ceiling must be insulated from underneath. In this case there is the possibility to apply another airtight barrier there, which again has to be carefully attached and sealed to the abutting walls and columns.

Different measures can be combined to achieve better tightness. An injection into areas of highly porous basement walls to make them tight is a "last solution". The technique is well known to water-tighten walls and footings below grade and inhibit rising water from the ground. If all measures are taken the result may be 150% effective. But in most cases not all of them are possible (or payable..) and still 100 % can be achieved.

Electric wiring and other things which penetrate the whole wall

The electric plug only covers the problem.

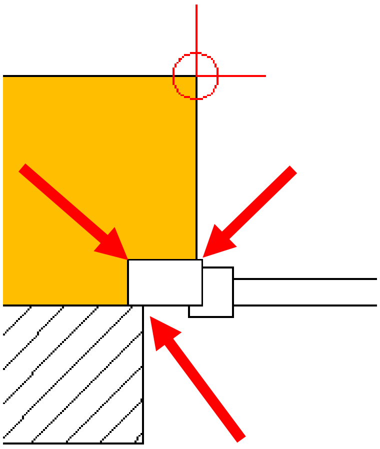

Figure 3.3-4
Sealing a window to the airtightness layer: improved inside plastering or old but im
.

Inside are cable ducts penetrating the airtight plane and providing a channel where air can leak. To avoid this, empty cable ducts must be closed off and cable ducts with wires have to be sealed. A mastic is used which is and remains flexible so that it can be removed when necessary.

Joints to the roof

Sloping roofs are very common in older buildings. The roofing is carried by rafters over wooden beams. Standard practice is to pack insulation between the rafters. But a high performance renovation requires a minimum of 20 cm insulation thickness (more is desirable in most climates). Three solutions are common:

- The roofing (mostly tile) is removed and an additional layer of insulation laid over the roof decking.
- A second layer of insulation is installed below and covering the rafters, if the ceiling height of the attic is still acceptable.

In both cases an airtight foil should be applied beneath the rafters (and the insulation layers) and sealed to any attic walls, vent pipe and chimney penetrations to achieve an airtight barrier. The foil must be self-healing because the finish ceiling must be anchored through to the rafters.

In rare cases if the rafters have to stay visible, all the insulation has to go on top of the roof decking, which looks rather massive at the roof edges from the outside. Furthermore achieving air tightness is complex, because every rafter is penetrating the airtight plane.

- The attic floor can be insulated, if the attic can stay cold and / or ceiling height of the attic is still acceptable. Air tightness of the attic floor is achieved as is done for the floor above a basement, just upside down, namely:

1. Apply a foil before installing a new finish ceiling for the rooms below the attic.

2. Air tight the attic floor before installing the insulation on top. Here, again care is essential for sealing between the floor at all edges of walls, columns or supporting walls in the air tight plane.

3. Wind tight the attic and / or make the attic floor insulation wind tight on top.

If the attic floor is concrete, it should be sufficiently air tight but must be checked (particularly at the edges and penetrations). Measure 2 and 3 may be adequate if 1 is infeasible. Comply with the basic principle: Vapour resistance diminishes towards the cold side.

Supervision on building site necessary

Making an old building airtight requires good planning and high quality products, but these will be insufficient if the installation is not very well executed. Therefore skilled craftsmen are needed, who got a special instruction about the effect and the details of air tightness. In addition a good supervision of craftsmen on the building site is essential to assure that all the planning is realized appropriately

Summary

Good air tightness of the building envelope is essential for an overall good energetic performance of the renovated building. Good air tightness is a planning task: To achieve good results, it is necessary to provide an accurate planning especially for critical junction details. If these are not solved in advance the best craftsmen cannot repair a missing conception and planning on the building site.

References

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[55] [AKKP 24] Einsatz von Passivhaustechnologien bei Altbaumodernisierung, Protokollband Nr. 24, Passivhaus Institut, www. passiv.de

[56] [passipedia] The Passive House Resource: information about energy efficient building design, www.passipedia.org

[57] [Jean-Paul-Platz]. See project brochure at the IEA Task 37 website: www.iea-shc.org/task37.
A full report is available at www.passiv.de.

3.4 Examples for detailed design of critical junctions

Berthold Kaufmann, Wolfgang Hasper

In this section some examples of detailed design of junctions shall be presented, which have been used and evaluated in already realized projects [64][HMWi 2009].

These examples may be used as a catalogue of thermal bridges. Therefore all information which is needed to characterize the thermal bridge effect of a junction is provided: The U-values of the adjacent parts of a junction (wall, ceiling or roof), the thermal conductivities (λ [W/mK]) of used materials and the dimension mainly of thermal insulation layer thickness.

3.4.1 Cellar ceiling

Though, not a thermal bridge the design of cellar ceiling insulation is crucial for renovation projects. In most cases the free height of a cellar of existing buildings is not much more than about 220 cm sometimes even less. This means, that any insulation layer added from below to the ceiling must not be much thicker than about 10 cm otherwise the remaining free height would be not enough.

Crucial points are the construction elements which bear the cladding of the ceiling. These elements may not be out of metal beams or metal C-Profiles because these would lead to severe thermal bridge effects. This is shown by the following graphs and effective U-values for several construction types.

In addition to understand the following thermal bridge survey, these examples of cellar ceiling insulation are instructive.

Description and remarks are given for each figure.

Figure 3.4-1
Realized insulation Tevesstraße.

[MHWI 2009]

Cellar ceiling insulation not disturbed by beams or fixings of cladding

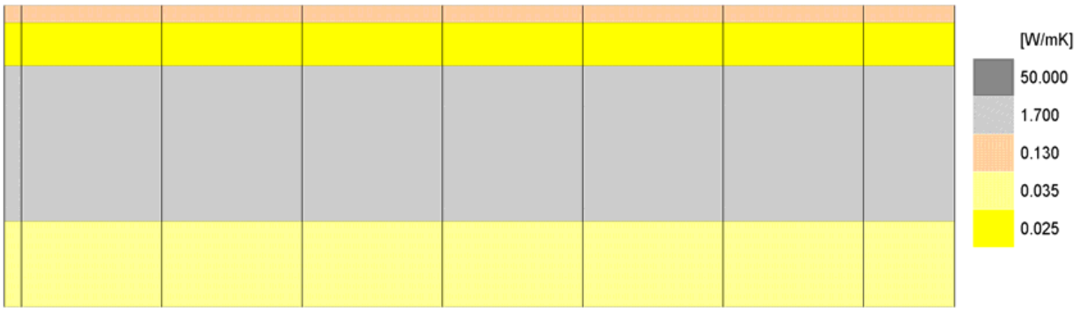


Figure 3.4-2
Ideal cellar ceiling insulation. No thermal bridge effects by fastening elements considered

[HMWi 2009]

50 mm PU (λ = 0,025 W/(mK)) on top concrete slab, 100 mm PS (λ = 0,035 W/(mK)) beneath concrete slab U = 0,183 W/(m²K)

Cellar ceiling insulation with C-studs

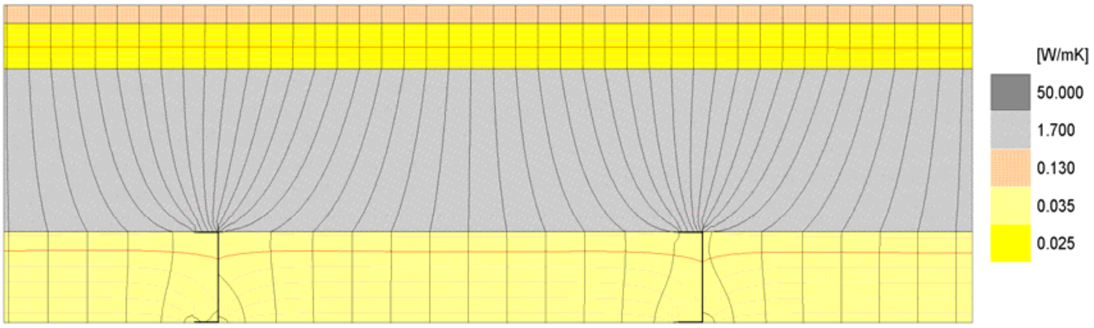


Figure 3.4-3
Fastening of insulation / cladding on steel C-studs.

Severe thermal bridge effect.

[HMWi 2009]

C-studs penetrate lower insulation layer, distance 60 cm.
U = 0,242 $W/(m^2K)$ ΔU = 0,06 $W/(m^2K)$ equivalent to –50 mm insulation thickness

Cellar ceiling insulation with C-studs improved I

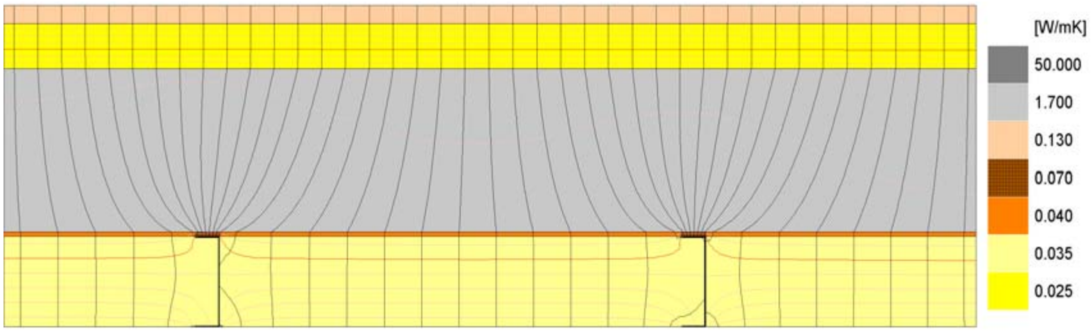


Figure 3.4-4
Fastening of insulation / cladding on steel C-studs with separation layer (Thermostopp).

Reduced but still considerable thermal bridge effect.

[HMWi 2009]

C-studs penetrate lower insulation layer, distance 60 cm. Underlay Thermostopp 5 mm.
U = 0,226 $W/(m^2K)$ ΔU = 0,04 $W/(m^2K)$ equivalent –40 mm insulation thickness

Cellar ceiling insulation with C-studs improved II

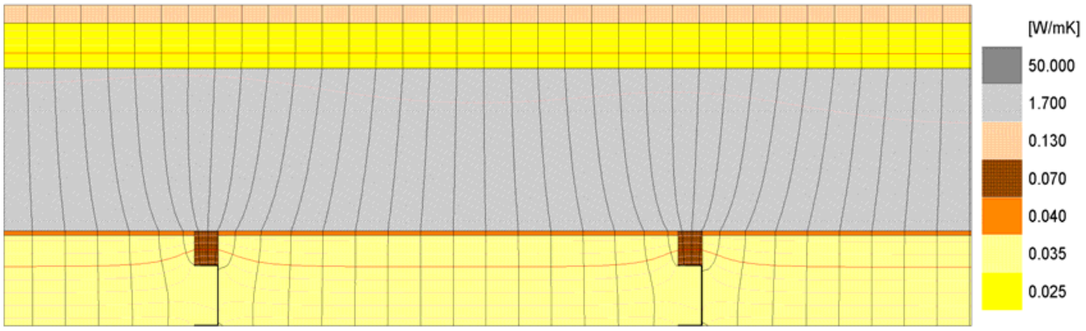


Figure 3.4-5
Fastening of insulation / cladding on steel C-studs with separation layer (battens)

Reduced but still considerable thermal bridge effect.

[HMWi 2009]

C-studs penetrate only 2/3 of lower insulation layer, distance 60 cm. Underlay wood battens 35 mm.
U = 0,200 $W/(m^2K)$ ΔU = 0,02 $W/(m^2K)$ equivalent –20 mm insulation thickness

Cellar ceiling insulation with wooden beams

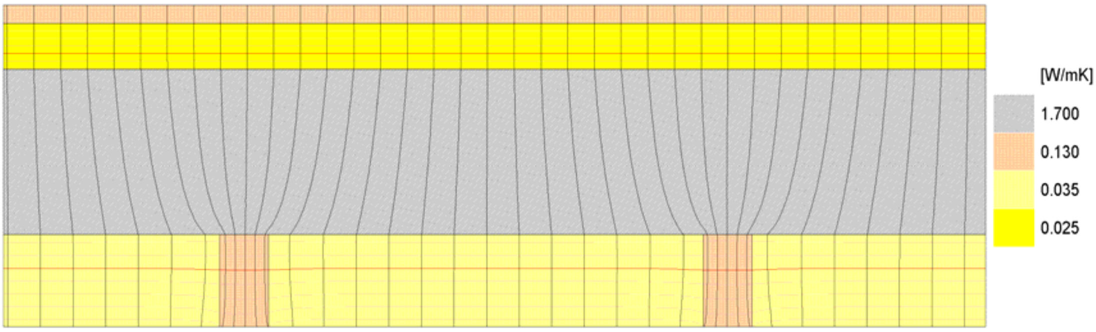


Figure 3.4-6
Fastening of insulation / cladding on wooden beams

Reduced but still considerable thermal bridge effect.

[HMWi 2009]

Wooden beams 60 x 100 mm penetrate lower insulation layer, distance 60 cm.
U = 0,204 W/(m^{2}K) ΔU = 0,02 W/(m^{2}K) this is equal to about –20 mm insulation layer thickness

Cellar ceiling insulation wirh metal bars

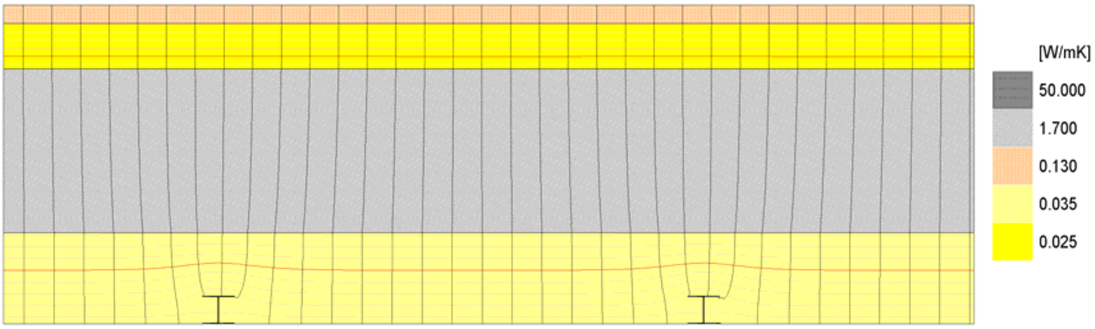


Figure 3.4-7
insulation glued to cellar ceiling, panels connected bx metal bars.

Reduced thermal bridge effect.

[HMWi 2009]

Metal bars penetrate only 1/3 of lower insulation layer, distance 60 cm.
U = 0,188 W/(m^{2}K) ΔU = 0,005 W/(m^{2}K) equivalent –5 mm insulation thickness.

Cellar ceiling insulation with plastic bars

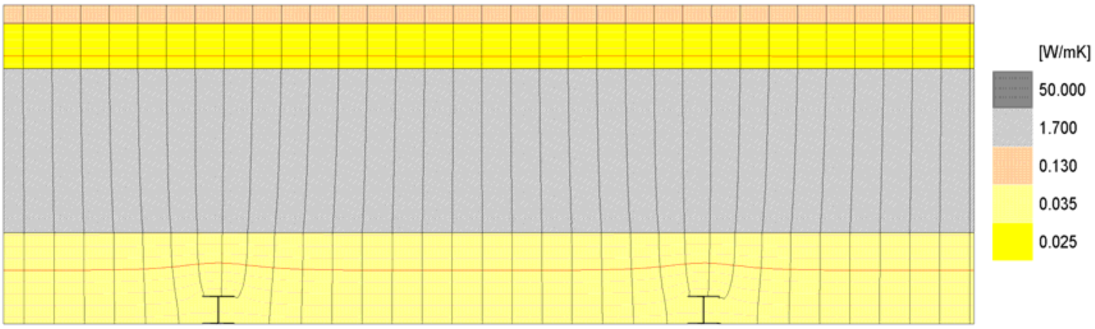


Figure 3.4-8
insulation glued to cellar ceiling, panels connected bx plastic bars.

Virtually no thermal bridge effect.

[HMWi 2009]

Plasic bars penetrate only 1/3 of lower insulation layer, distance 60 cm.
U = 0,183 W/(m^{2}K) ΔU = 0,000 W/(m^{2}K) virtually no thermal bridge effect

Cellar ceiling insulation with plastic bars – reduced thickness

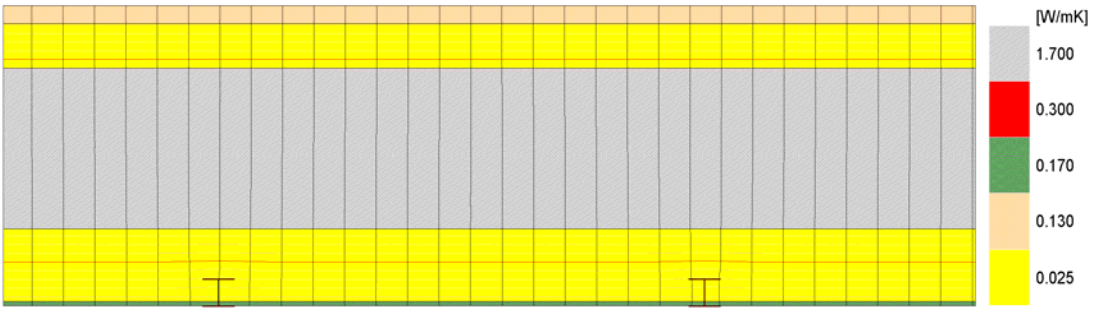


Figure 3.4-9
To save room height PU-insulation panels (025) are used. Panels connected bx plastic bars and laminated with hardboard for mechanical protection. Realized solutin in Tevesstrasse.

Virtually no thermal bridge effect.

[HMWi 2009]

Lower insulation layer from laminated PU-insulation panels 80 mm (λ = 0,025 W/(mK)).
Panels fastened with special screws and plugs. Panels connected by plastic H- bars (λ = 0,3 W/(mK) in prefabricated channels
U = 0,177 W/(m^{2}K) ΔU = 0,000 W/(m^{2}K) virtually no thermal bridge effect

3.4.2 Basement wall

Thermal bridge issues are frequently encountered at the basement wall: Given the prevalent case of an unheated cellar the load bearing wall penetrates the insulation layer. Thermal separation layers that are common in new construction cannot be retrofitted with reasonable costs. The following case study shows a variety of designs and their properties related to building physics.

As can be seen clearly from the several examples it is absolutely necessary to 'wrap' the thermal bridge at cellar ceiling and outside wall as good as possible, thus having insulation below the cellar ceiling.

The same is true for internal cellar walls bearing the cellar ceiling. An extra band of insulation about 30 cm wide should be installed along all the walls below the ceiling. See Figure 3.4-23 and following. Much more is not necessary.

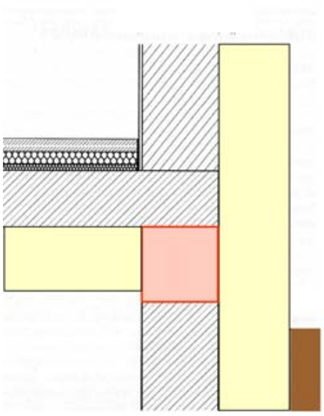
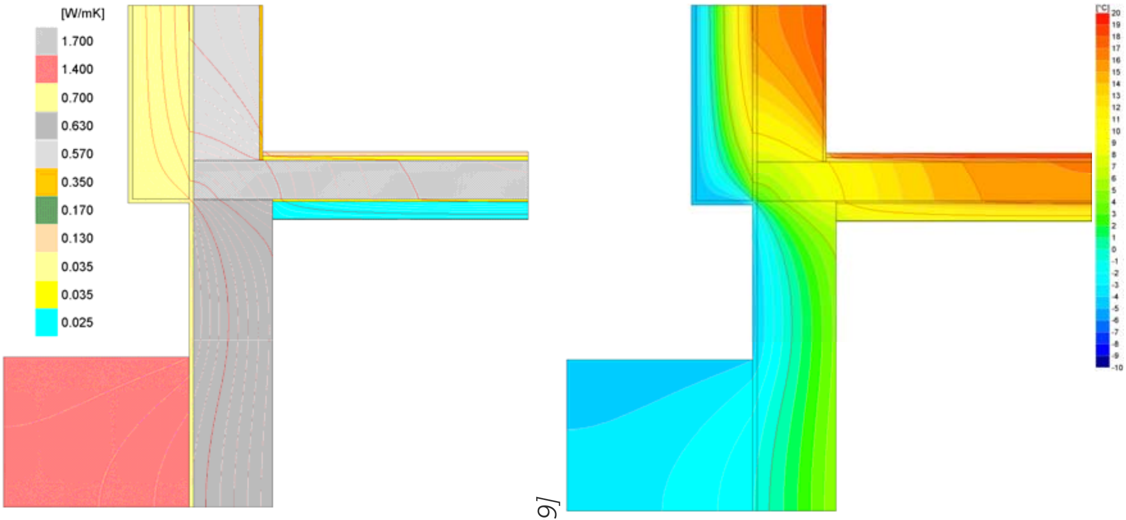


Figure 3.4-10
Thermal separation of basement wall with material of low thermal conductivity (e.g. porous concrete ⍰<0,25 W/(mK))

Base not insulated - unusable



[HMWi 2009]

Figure 3.4-11
Materials/isotherm image

Temperatures image
Inside and outside of the basemet wall without insualtion. This configuration would be <u>unusable</u> due to extremely high thermal bridge effect and consecutively low surface temperatures on the inside leading to condensate and mould.

Boundary conditions:

exterior wall U= 0,122 W/(m²K

260 mm 0,035 W/(mK)

cellar ceiling U=0,214 W/(m²K)

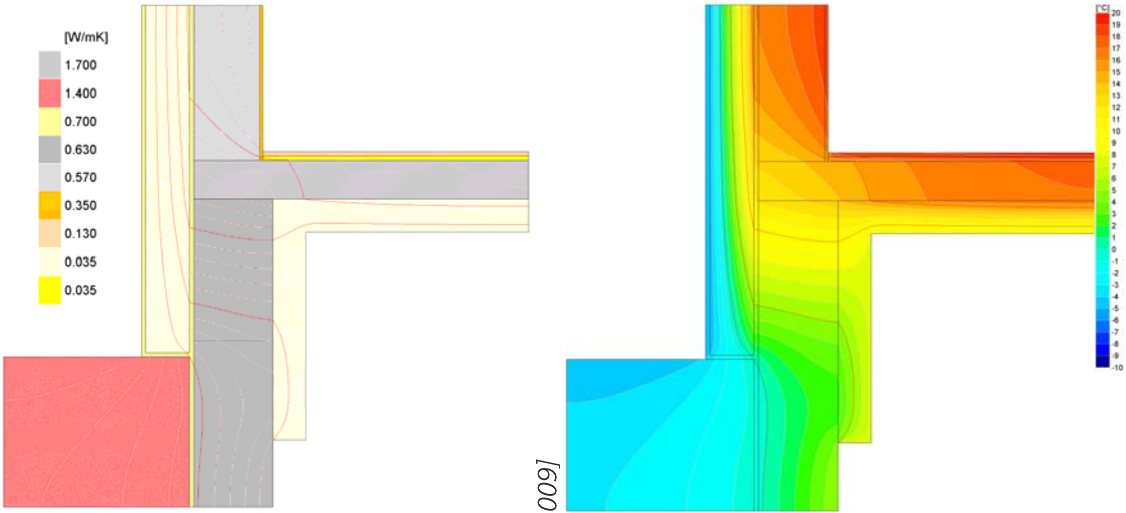
80 mm 0,025 W/(mK)

Resulting thermal bridge effect:

Ψa = 0,324 W/(mK)

ϑmin = 9,9 °C

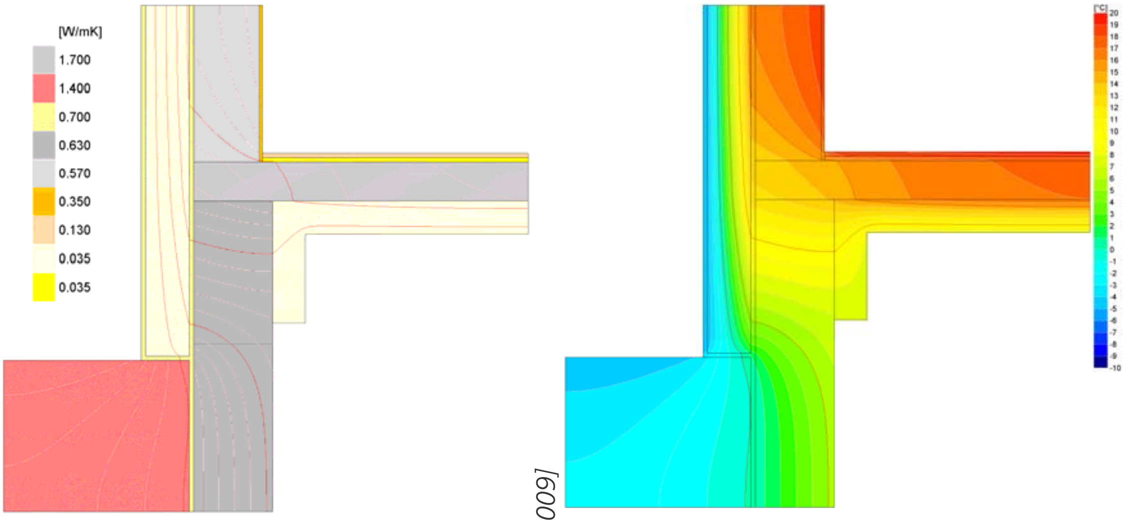
Base insulated 1.1



[HMWi 2009]

Figure 3.4-12
Materials/isotherm image **(left)**
Temperatures image
Inside of exterior wall and cellar ceiling insulated, exterior wall and base insulated down to ground.
Boundary conditions:
exterior wall U =0,154 W/(m²K)
200 mm 0,035 W/(mK)
cellar ceiling U = 0,183 W/(m²K) 150 mm 0,035 W/(mK)
Insulation on inside of exterior wall 110 cm down from cellar ceiling
Resulting thermal bridge effect:
Ψa = 0,074 W/(mK)
ϑmin = 14,52 °C

Base insulated 1.2

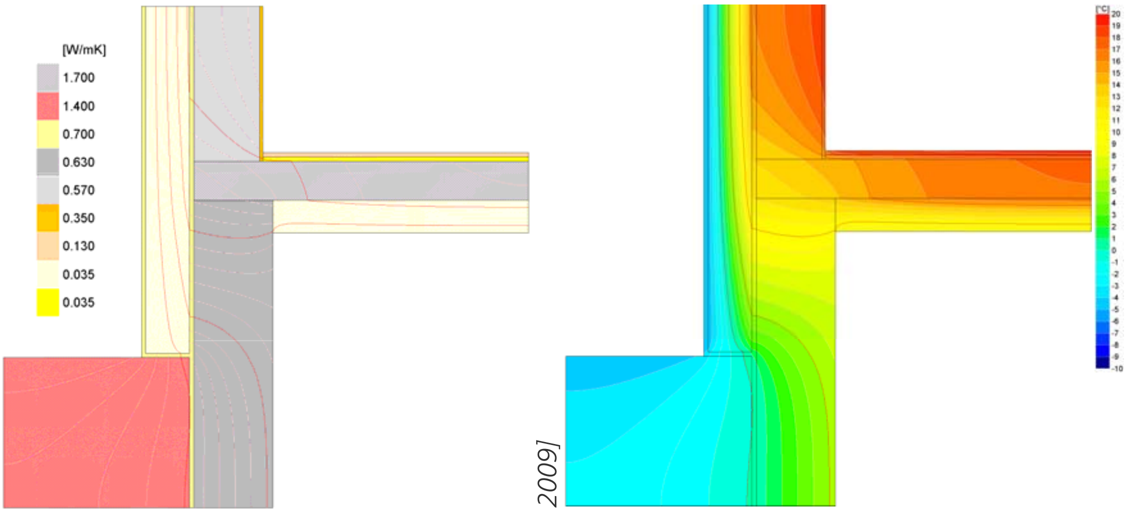


[HMWi 2009]

Figure 3.4-13
Materials/isotherm image

Temperatures image
Inside of exterior wall and cellar ceiling insulated, exterior wall and base insulated down to ground.
Boundary conditions:
exterior wall U =0,154 W/(m²K)
200 mm 0,035 W/(mK)
cellar ceiling U = 0,183 W/(m²K) 150 mm 0,035 W/(mK)
Insulation on inside of exterior wall 55 cm down from cellar ceiling
Resulting thermal bridge effect:
Ψa = 0,058 W/(mK)
ϑmin = 14,82 °C

Base insulated 1.3



[HMWi 2009]

Figure 3.4-14
Materials/isotherm image

Temperatures image exterior wall and cellar ceiling insulated, exterior wall and base insulated down to ground.

Boundary conditions:

exterior wall U =0,154 W/(m²K) 200 mm 0,035 W/(mK)

cellar ceiling U = 0,183 W/(m²K) 150 mm 0,035 W/(mK)

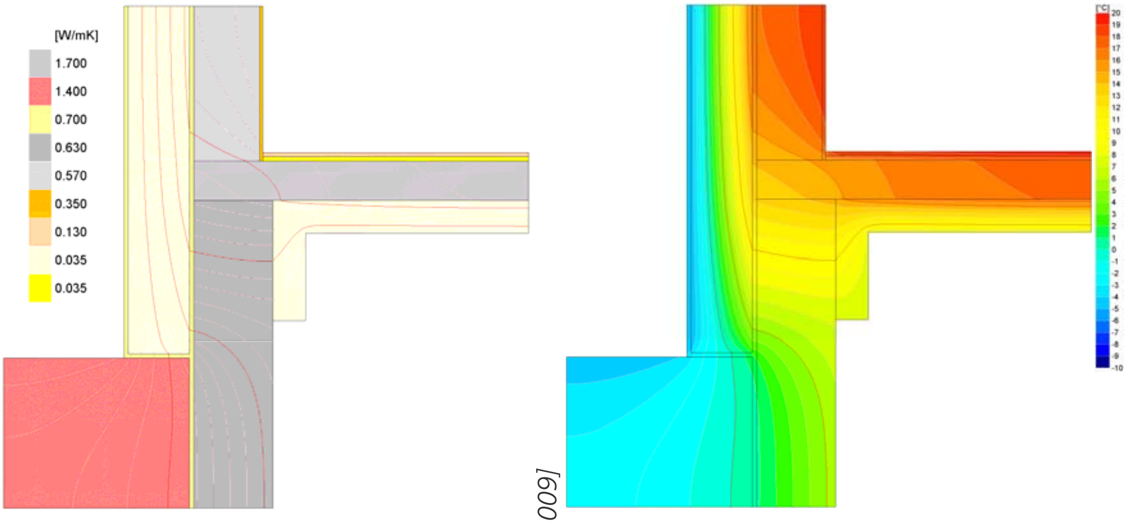
No insulation on inside of exterior wall

Resulting thermal bridge effect:

Ψa = 0,087 W/(mK)

ϑmin = 14,45 °C

Base insulated 2.1



MWi 2009]

Figure 3.4-15
Materials/isotherm image

Temperatures image exterior wall and cellar ceiling insulated, exterior wall and base insulated down to ground.

Boundary conditions:

exterior wall U =0,107 W/(m²K) 300 mm 0,035 W/(mK)

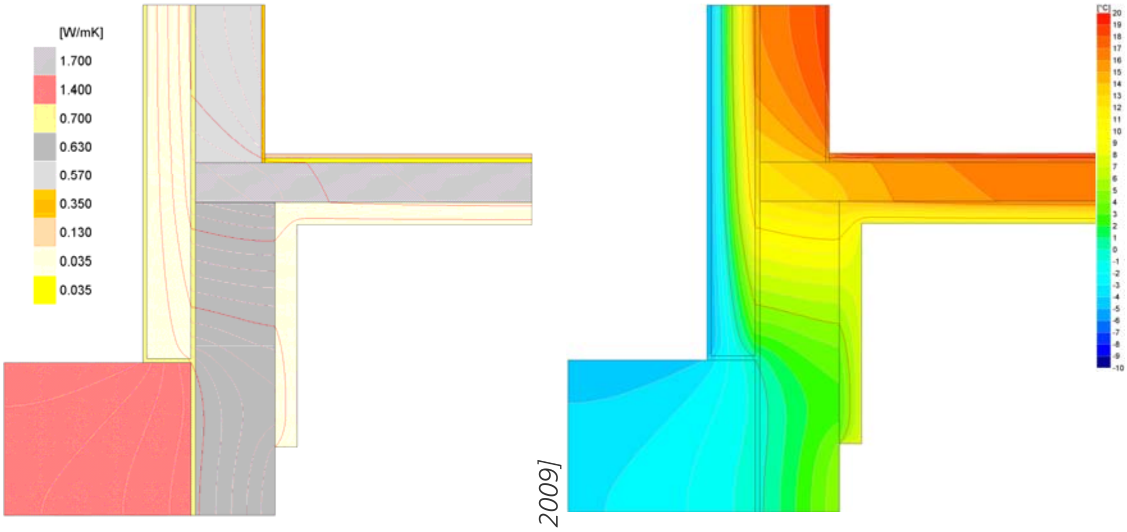
cellar ceiling U = 0,183 W/(m²K) 150 mm 0,035 W/(mK)

Insulation on inside of exterior wall 55 cm down from cellar ceiling

Resulting thermal bridge effect:

Ψa = 0,071 W/(mK)

Base insulated 3.1



[HMWi 2009]

Figure 3.4-16
Materials/isotherm image

Temperatures image
exterior wall and cellar ceiling insulated, exterior wall and base insulated down to ground.

Boundary conditions:

exterior wall U =0,154 W/(m²K)

200 mm 0,035 W/(mK)

cellar ceiling U = 0,249 W/(m²K) 100 mm 0,035 W/(mK)

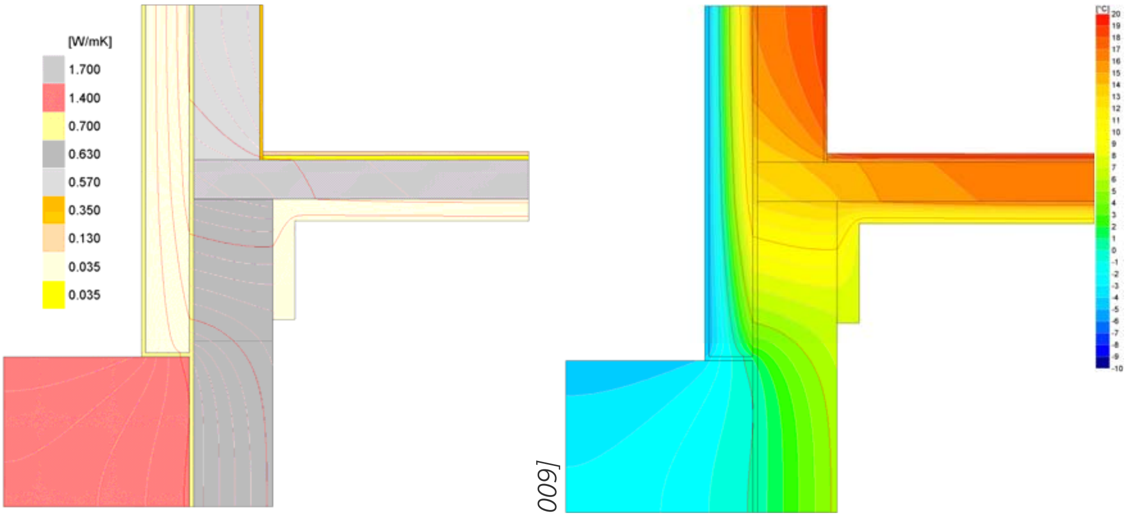
Insulation on inside of exterior wall 110 cm down from cellar ceiling

Resulting thermal bridge effect:

Ψa = 0,049 W/(mK)

ϑmin = 14,27 °C

Base insulated 3.2



[HMWi 2009]

Figure 3.4-17
Materials/isotherm image

Temperatures image
exterior wall and cellar ceiling insulated, exterior wall and base insulated down to ground.

Boundary conditions:

exterior wall U =0,154 W/(m²K)

200 mm 0,035 W/(mK)

cellar ceiling U = 0,249 W/(m²K) 100 mm 0,035 W/(mK)

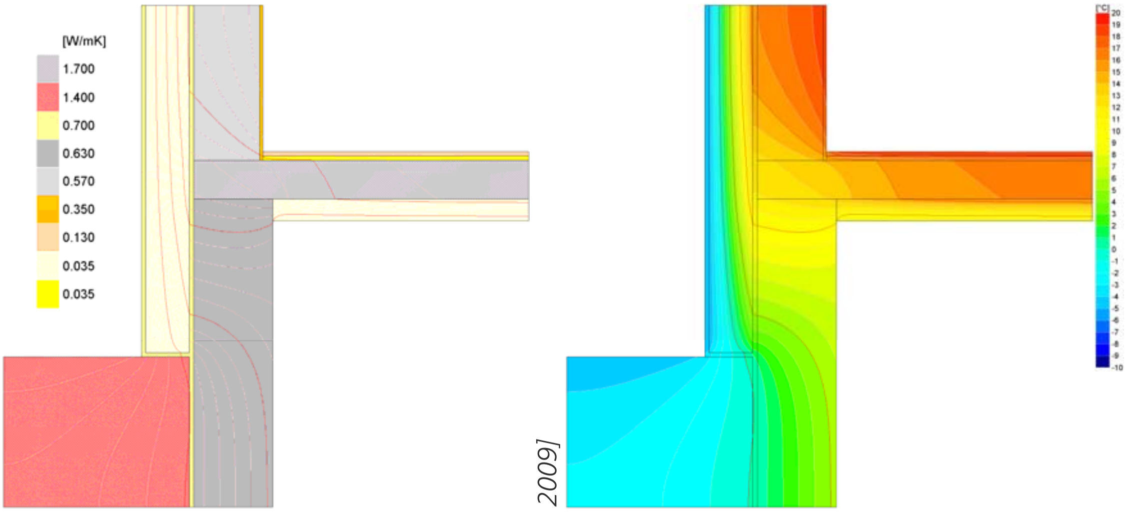
Insulation on inside of exterior wall 55 cm down from cellar ceiling

Resulting thermal bridge effect:

Ψa = 0,035 W/(mK)

ϑmin = 14,53 °C

Base insulated 3.3



[HMWi 2009]

Figure 3.4-18
Materials/isotherm image

Temperatures image
exterior wall and cellar ceiling insulated, exterior wall and base insulated down to ground.

Boundary conditions:

exterior wall U =0,154 W/(m^{2}K)

200 mm 0,035 W/(mK)

cellar ceiling U = 0,249 W/(m^{2}K) 100 mm 0,035 W/(mK)

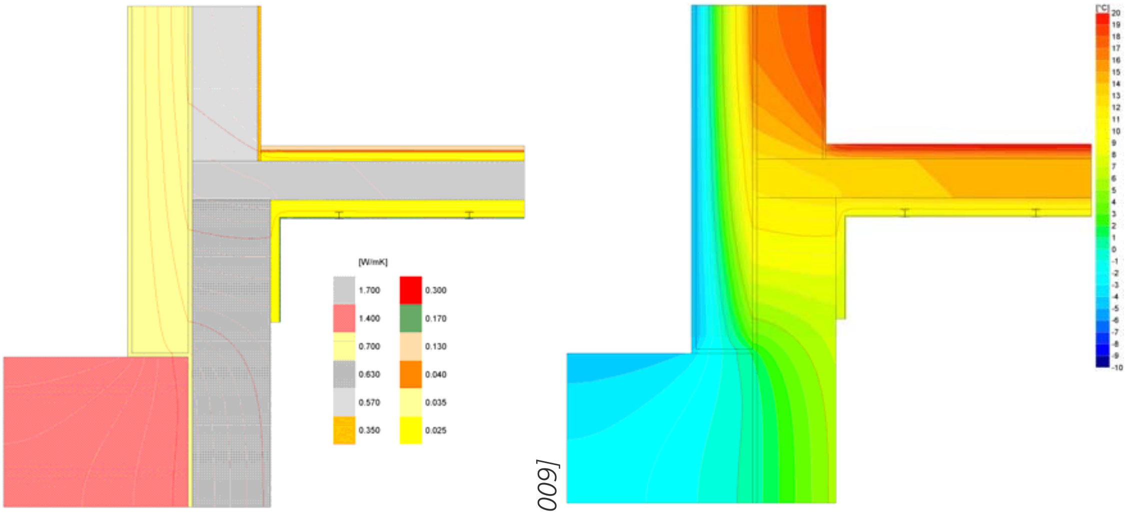
No insulation on inside of exterior wall

Resulting thermal bridge effect:

Ψa = 0,069 W/(mK)

ϑmin = 14,08 °C

Base insulated 4.1



[HMWi 2009]

Figure 3.4-19
Materials/isotherm image

Temperatures image
exterior wall and cellar ceiling insulated, exterior wall and base insulated down to ground.

Boundary conditions:

exterior wall U =0,122 W/(m^{2}K)

260 mm 0,035 W/(mK)

cellar ceiling U = 0,177 W/(m^{2}K) 50+80 mm 0,025 W/(mK)

Insulation on inside of exterior wall 55 cm down from cellar ceiling

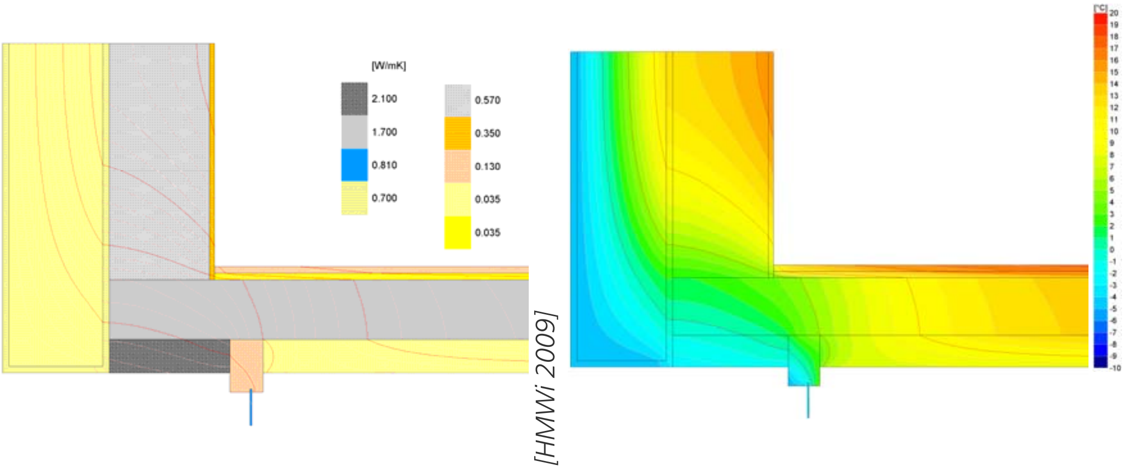
Resulting thermal bridge effect:

Ψa = 0,046 W/(mK)

ϑmin = 13,40 °C

Realized solution in project Tevesstrasse, cf. Fig. 1 **and** Fig. 9 **Insulation of basement wall (inside) 40 mm 0,025 W/(mK) laminated with hardboard**

Basement door lintel not insulated – unusable I

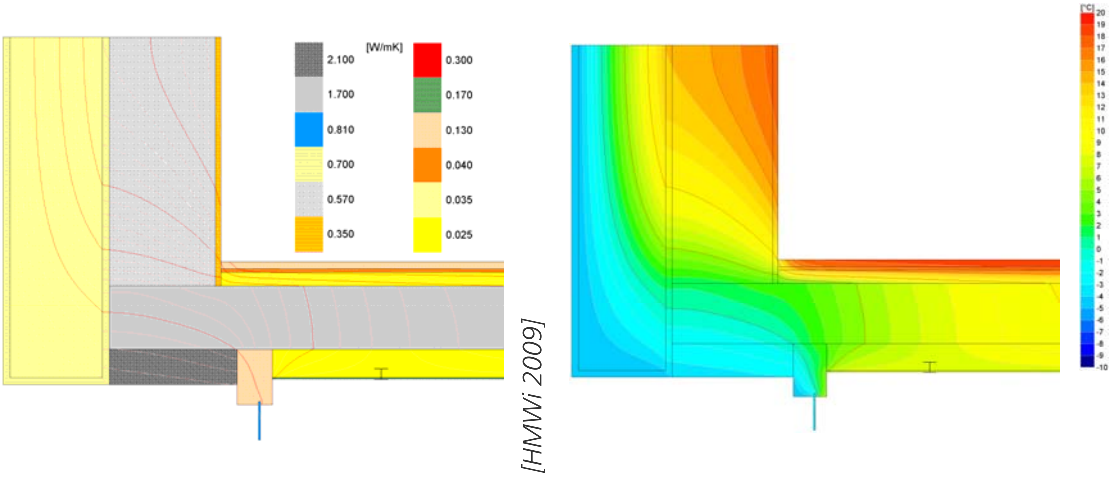


[HMWi 2009]

Figure 3.4-20
Materials/isotherm image

Temperatures image
Basement door lintel; concrete, not insulated.
Boundary conditions:
exterior wall U =0,107 W/(m²K) 300 mm 0,035 W/(mK)
cellar ceiling U = 0,249 W/(m²K) 20+100 mm 0,035 W/(mK)
Resulting thermal bridge effect:
Ψa = 0,467 W/(mK) [!]
ϑmin = 4,00 °C

Basement door lintel not insulated – unusable II

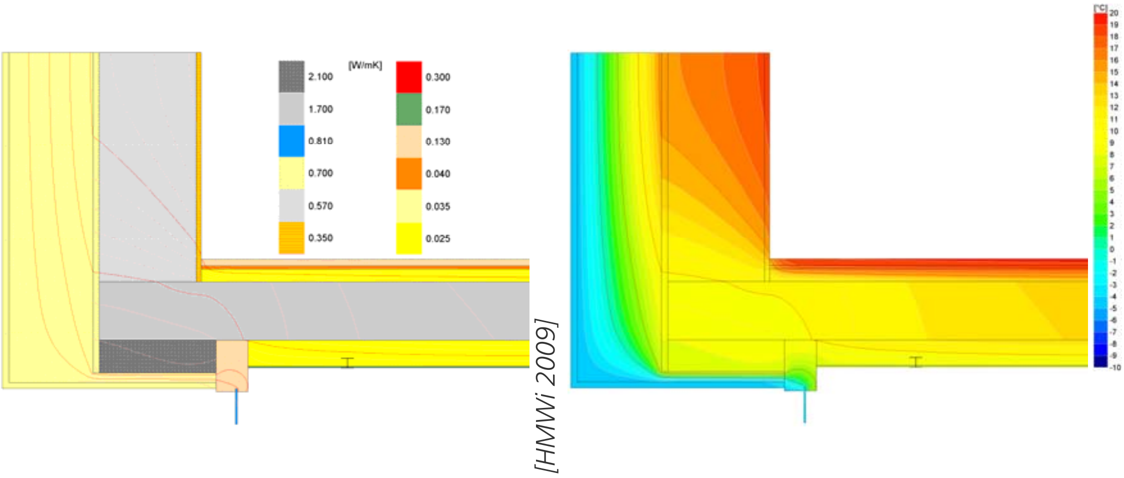


[HMWi 2009]

Figure 3.4-21
Materials/isotherm image

Temperatures image
Basement door lintel; concrete, not insulated.
Boundary conditions:
exterior wall U =0,122 W/(m²K) 260 mm 0,035 W/(mK)
cellar ceiling U = 0,177 W/(m²K) 50+80 mm 0,025 W/(mK)
Resulting thermal bridge effect:
Ψa = 0,468 W/(mK) [!]
ϑmin = 2,70 °C

Basement door lintel improved I

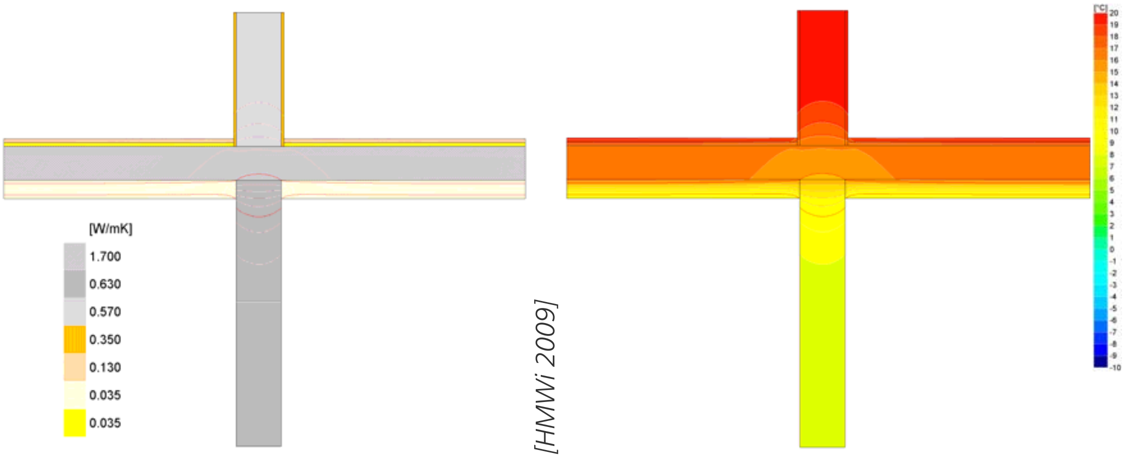


[HMWi 2009]

Figure 3.4-22
Materials/isotherm image

Temperatures image
Basement door lintel; concrete, insulated 30 mm 0,035 W/(mK)
Boundary conditions:
exterior wall U =0,122 W/(m²K) 260 mm 0,035 W/(mK)
cellar ceiling U = 0,177 W/(m²K) 50+80 mm 0,025 W/(mK)
Resulting thermal bridge effect: *Ψa = 0,163 W/(mK) [!]*
ϑmin = 10,30 °C

Interior basement wall – no escorting insulation

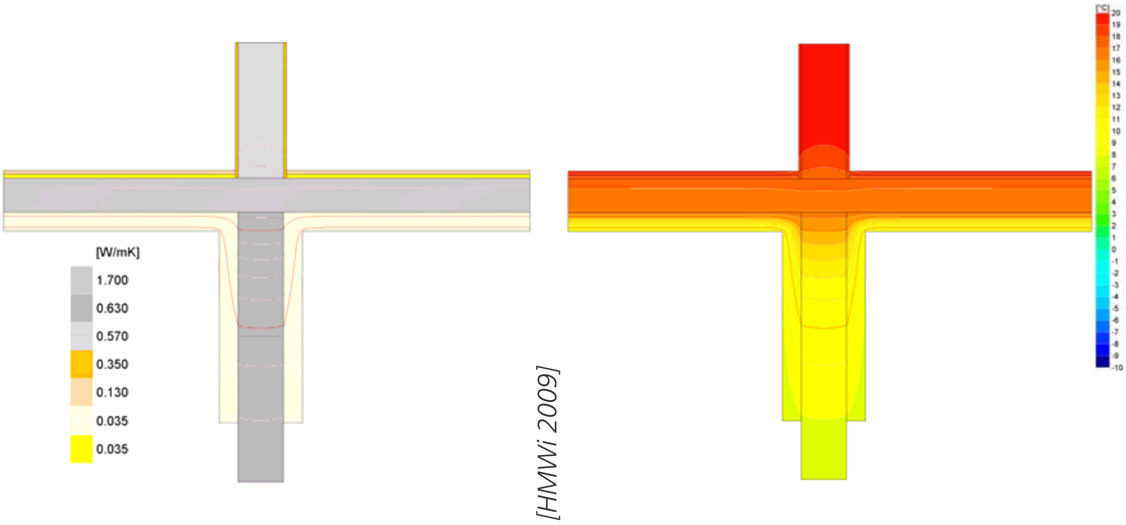


[HMWi 2009]

Figure 3.4-23
Materials/isotherm image

Temperatures image
Interior basement wall penetrates insulation layer at the cellar ceiling, no escorting insulation on basement wall
Boundary conditions:
cellar ceiling U = 0,177 W/(m²K) 100 mm 0,035 W/(mK)
Resulting thermal bridge effect:
Ψa = 0,322 W/(mK) [!]
ϑmin = 16,05 °C

Interior basement wall – with escorting insulation 1.1

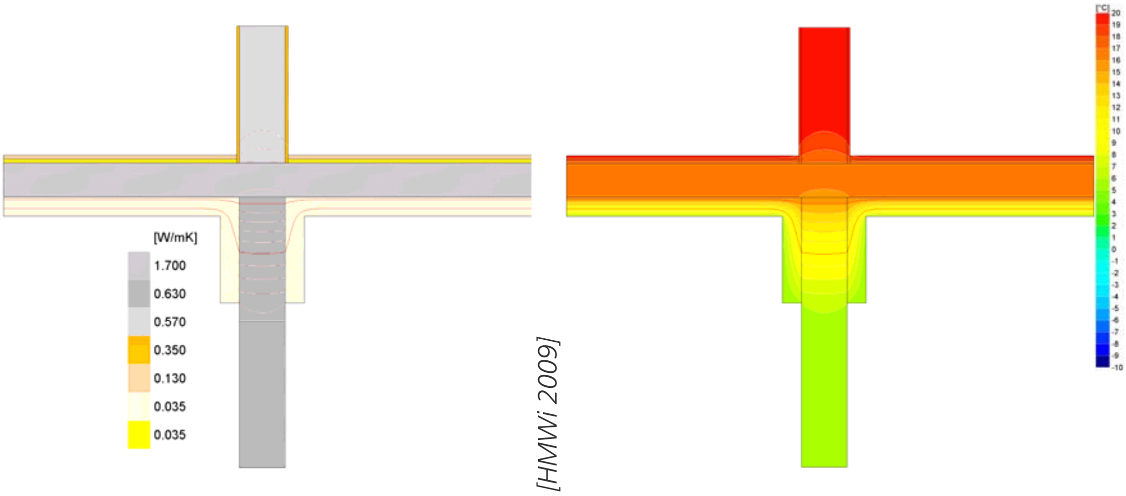


[HMWi 2009]

Figure 3.4-24
Materials/isotherm image

Temperatures image
Interior basement wall penetrates insulation layer at the cellar ceiling, escorting insulation on basement wall 110 cm down from cellar ceiling
Boundary conditions:
cellar ceiling U = 0,177 W/(m²K) 100 mm 0,035 W/(mK)
Resulting thermal bridge effect:
Ψa = 0,113 W/(mK) [!]
ϑmin = 17,10 °C

Interior basement wall – with escorting insulation 1.2

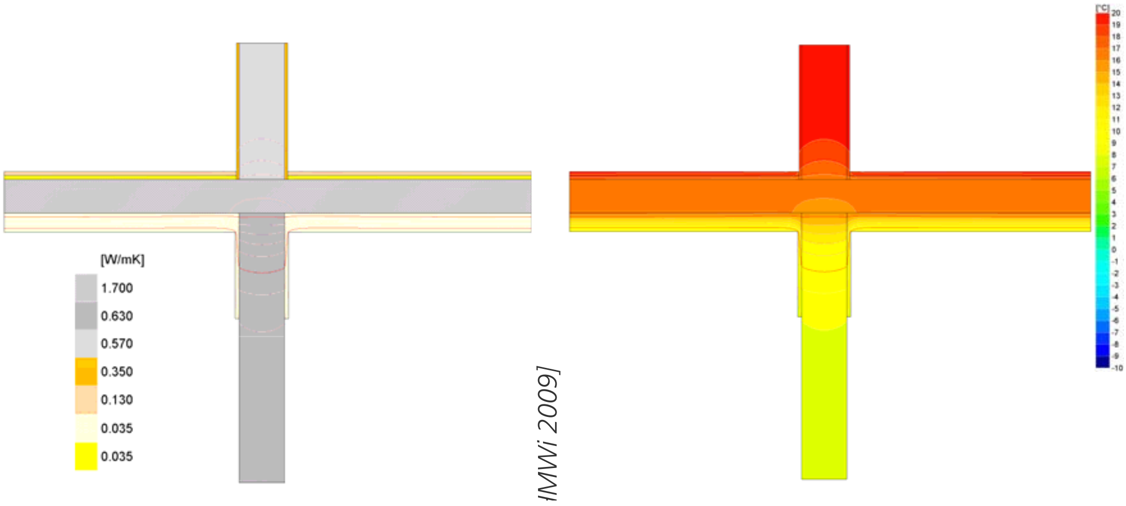


[HMWi 2009]

Figure 3.4-25
Materials/isotherm image

Temperatures image
Interior basement wall penetrates insulation layer at the cellar ceiling, escorting insulation on basement wall 55 cm down from cellar ceiling
Boundary conditions:
cellar ceiling U = 0,177 W/(m²K) 100 mm 0,035 W/(mK)
Resulting thermal bridge effect:
Ψa = 0,249 W/(mK) [!]
ϑmin = 16,62 °C

Interior basement wall – with escorting insulation 1.3



MWi 2009]

Figure 3.4-26
Materials/isotherm image

Temperatures image
Interior basement wall penetrates insulation layer at the cellar ceiling, escorting insulation on basement wall 55 cm down from cellar ceiling, 20 mm 0,035 W/(mK)

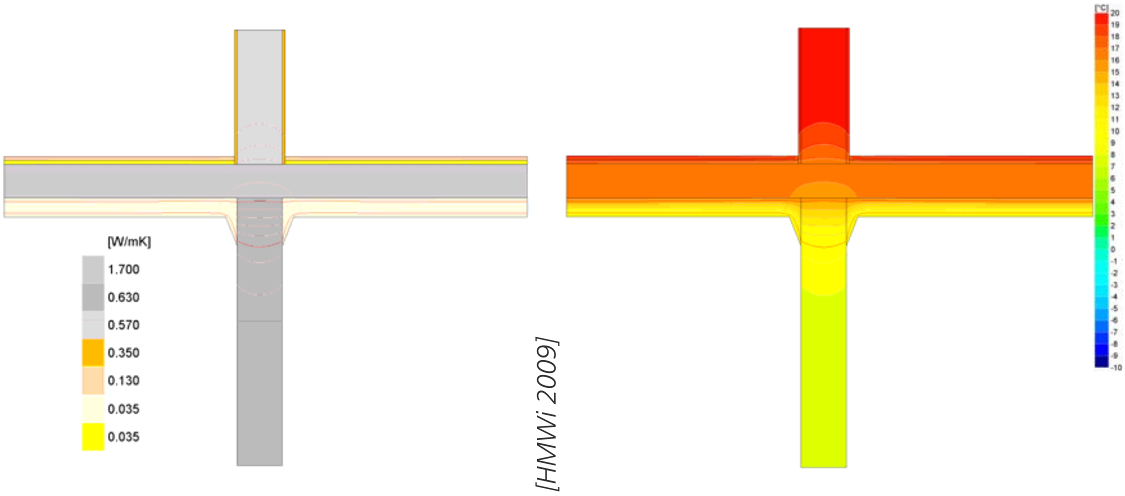
Boundary conditions:

cellar ceiling U = 0,177 W/(m²K) 100 mm 0,035 W/(mK)

Resulting thermal bridge effect:

Ψa = 0,249 W/(mK) [!]

Interior basement wall – with insulation wedge



[HMWi 2009]

Figure 3.4-27
Materials/isotherm image

Temperatures image
Interior basement wall penetrates insulation layer at the cellar ceiling, insulation wedge on basement wall 0,035 W/(mK)

Boundary conditions:

cellar ceiling U = 0,177 W/(m²K) 100 mm 0,035 W/(mK)

Resulting thermal bridge effect:

Ψa = 0,345 W/(mK) [!]

ϑmin = 16,50 °C

Interior basement wall – optimized detail

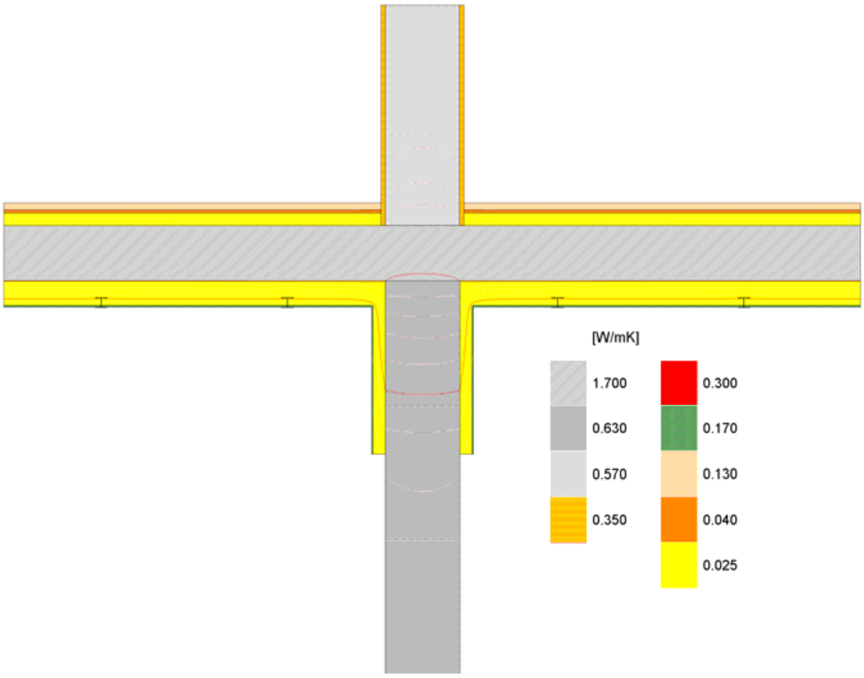


Figure 3.4-28
Materials/isotherm image

Interior basement wall penetrates insulation layer at the cellar ceiling,escorting insulation on basement wall 40mm 0,025 W/(mK)

Boundary conditions:

cellar ceiling U = 0,177 W/(m^{2}K) 50+80 mm 0,025 W/(mK)

Resulting thermal bridge effect:

Ψa = 0,185 W/(mK) [!]

ϑmin = 15,7 °C

[HMWi 2009]

Interior basement wall – optimized detail with cable conduit

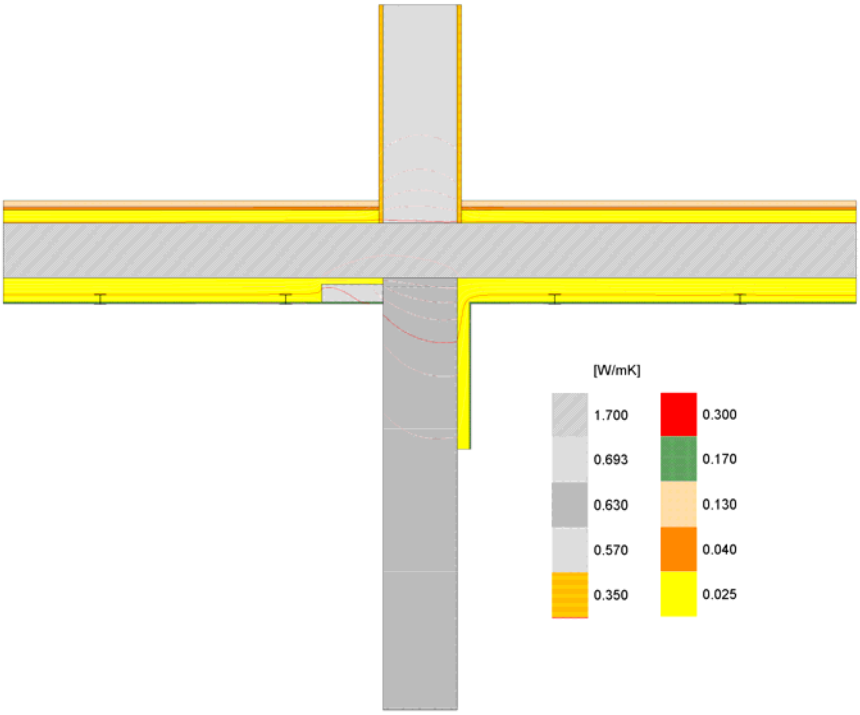


Figure 3.4-29
Materials/isotherm image

Interior basement wall penetrates insulation layer at the cellar ceiling,escorting insulation only on one side of basement wall 40mm 0,025 W/(mK)

Boundary conditions:

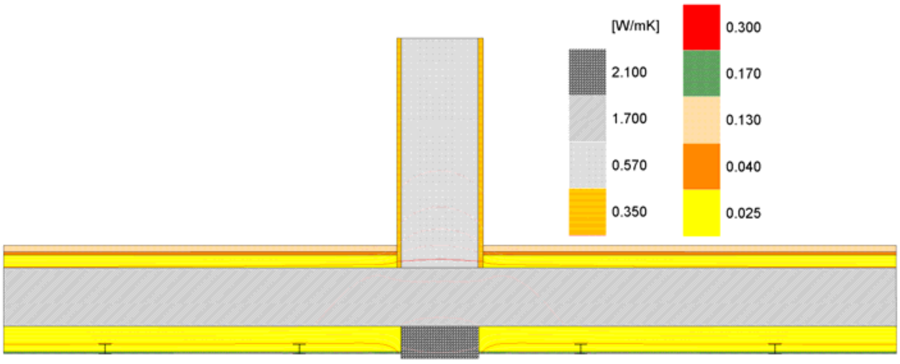
***cellar ceiling** U = 0,177 W/(m^{2}K) 50+80 mm 0,025 W/(mK)*

Resulting thermal bridge effect:
Ψa = 0,323 W/(mK) [!]

ϑmin = 14,6 °C

[HMWi 2009]

Interior basement wall – door lintel



[HMWi 2009]

Figure 3.4-30
Materials/isotherm image

Interior basement wall penetrates insulation layer at the cellar ceiling, due to limited door height no insulation is possible on the concrete lintel.

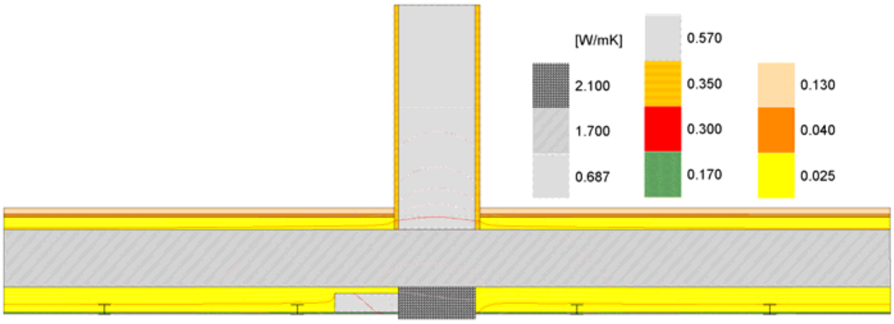
Boundary conditions:

***cellar ceiling** U = 0,177 W/(m²K) 50+80 mm 0,025 W/(mK)*

Resulting thermal bridge effect:
Ψa = 0,406 W/(mK) [!]

ϑmin = 12,8 °C

Interior basement wall – door lintel and cable conduit



[HMWi 2009]

Figure 3.4-31
Materials/isotherm image

Interior basement wall penetrates insulation layer at the cellar ceiling, due to limited door height no insulation is possible on the concrete lintel. Cable conduit added.

Boundary conditions:

***cellar ceiling** U = 0,177 W/(m²K) 50+80 mm 0,025 W/(mK) weakened to 20 mm*

Resulting thermal bridge effect:
Ψa = 0,449 W/(mK) [!]

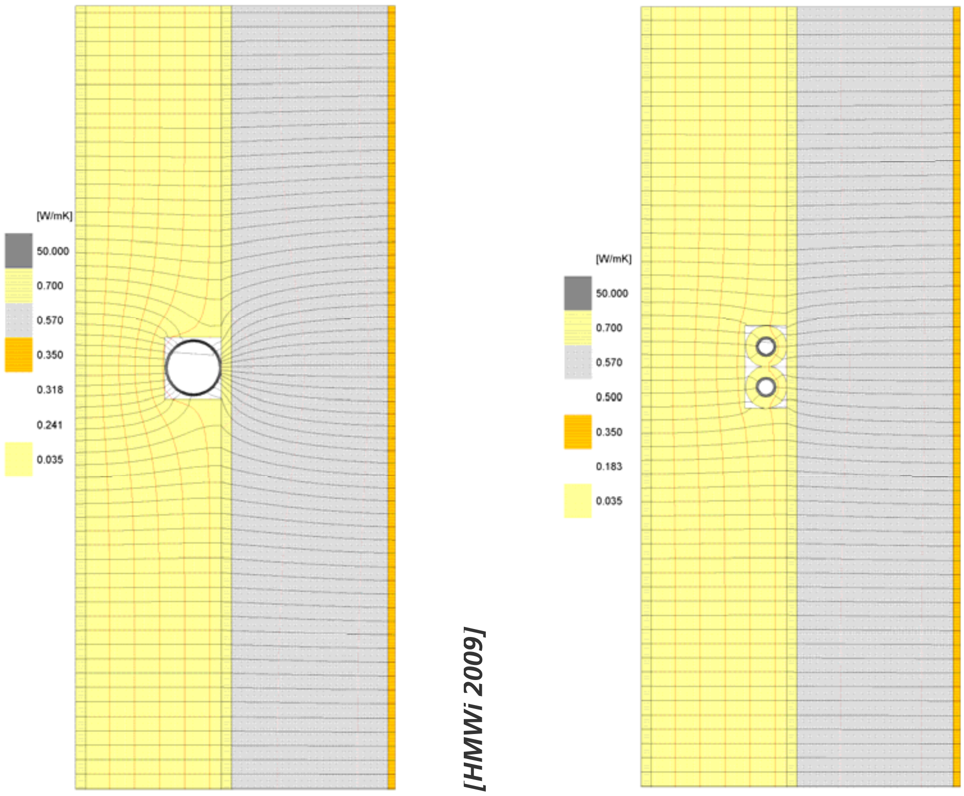
ϑmin = 13,8 °C

3.4.3 New instillations within the installation layer

If the outside wall is thermally insulated with a layer of more than 25 cm thickness, this gives enough room to install there waste water ducts, ducts for solar thermal collectors or simply cables.

As shown in Figure 3.4-32 a waste water duct or similar things will lead to slightly raised thermal bridge effects, but ψ-values are acceptable.

New installations within the installation layer



[HMWi 2009]

Figure 3.4-32
Materials/isotherm image

Cast iron drain pipe DN 100 within the insulation layer Boundary conditions:

***Exterior wall** U = 0,122 W/(m²K)*

260 mm 0,035 W/(mK)

***Resulting thermal bridge effect:** Ψa = 0,016 W/(mK)*

ϑmin = 16,35 °C

Materials/isotherm image

Solar thermal brine pipes within the insulation layer

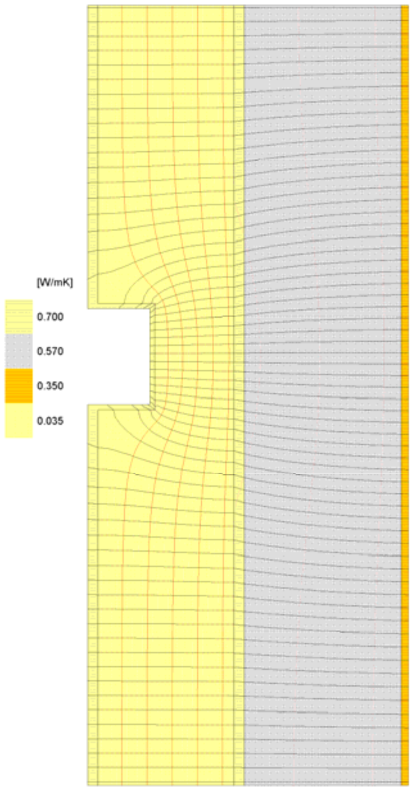
Boundary conditions:

***Exterior wall** U = 0,122 W/(m²K)*

260 mm 0,035 W/(mK)

***Resulting thermal bridge effect:** Ψa = 0,004 W/(mK)*

Recess for eaves gutter downpipe integration



[HMWi 2009]

Figure 3.4-33
Materials/isotherm image

Recess in insulation layer to incorporate rectangular downpipe (ext. wall along footpath)

Boundary conditions:

***Exterior wall** U = 0,122 W/(m²K)*

260 mm 0,035 W/(mK)

***Resulting thermal bridge effect:** Ψa = 0,025 W/(mK)*

ϑmin = 16,70 °C

3.4.4 Windows installation, theoretical basics

The most important issues for window installation with respect to thermal bridging are the same for old house renovation as for new buildings.

(1) The position of the window must fulfil that insulation layer of the window frame and that of the adjacent wall overlaps as good as possible. That means the window has to be best positioned in the plane of wall insulation. As the several examples show clearly: if this rule is not fulfilled and the new frame is placed at the old position in plane of the massive wall, the ψ values and thus the heat losses increase significantly, see Figure 3.4-38.

(2) The window frame should be covered by the wall-insulation as much as possible. This extra cover or overlap reduces the ψ-values significantly.

The dependence of both effects are indicated for a masonry in Figure 3.4-34, [55][AKKP 24], [6][AKKP37], and [56][passipedia].

If roller shutter are used in conventional configuration are used, the riling of the shutter is in conflict with the overlap of insulation. Insulated extra profiles as add-on to the frame profile with rails for the shutter are meanwhile available for some systems.

Window installation 2.1

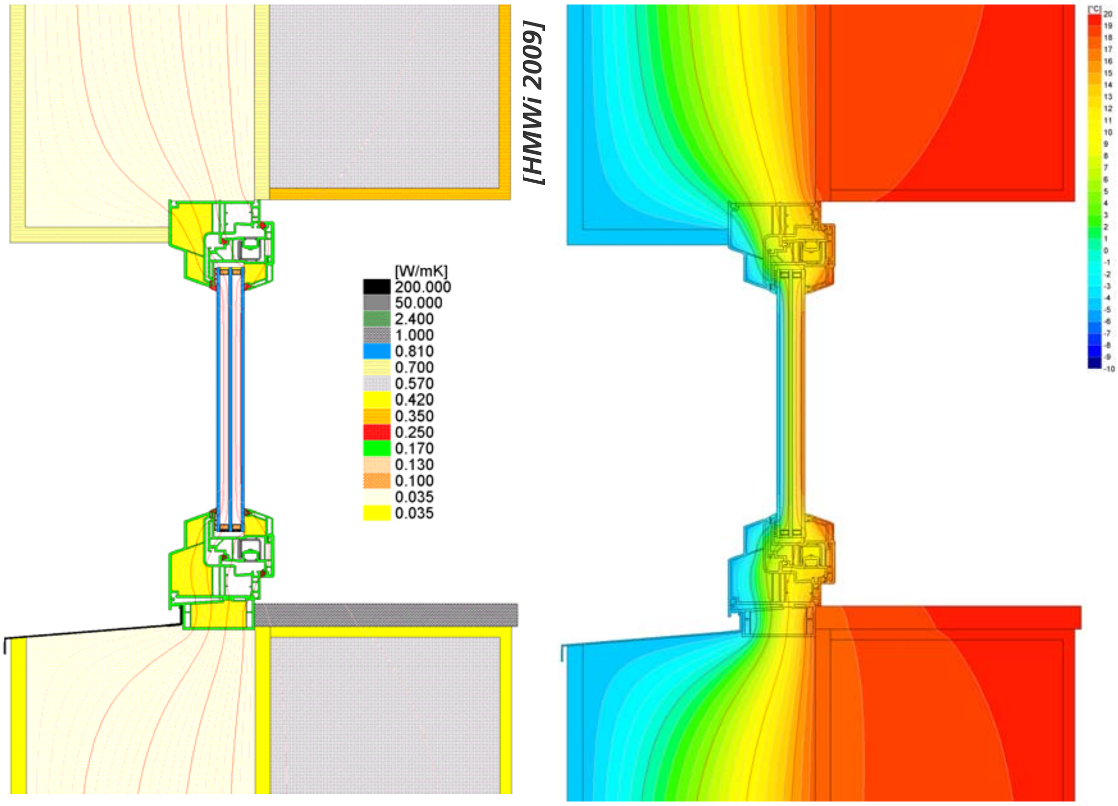


Figure 3.4-34
Materials/isotherm image

Temperatures image

Frame installed on outer surface of exterior wall, where possible covered by exterior wall insulation

Boundary conditions:
Exterior wall U = 0,107 W/(m²K)
300 mm 0,035 W/(mK)

Resulting thermal bridge effect:
$\Psi_{fixture}$ *(top/lateral) = 0,009 W/(mK)*
$\Psi_{fixture}$ *(bottom) = 0,042 W/(mK)*
mean: $\Psi_{fixture}$ *= 0,017 W/(m²K)*

U_W *= 0,84 W/(m²K)*
T_{min} *= 15,1 °C*
[HWWI 2009]

Window installation – insulation overlap

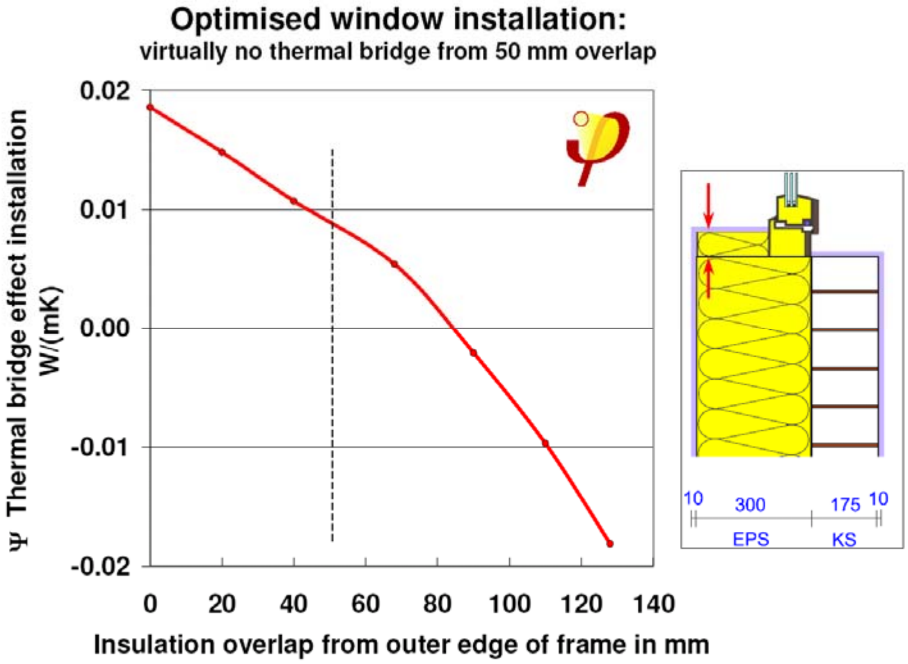


Figure 3.4-35
Window installation
Thermal bridge effect on insulation overlap on frame

[AKKP 14] [AKKP 37]

Window installation – position within insulation layer

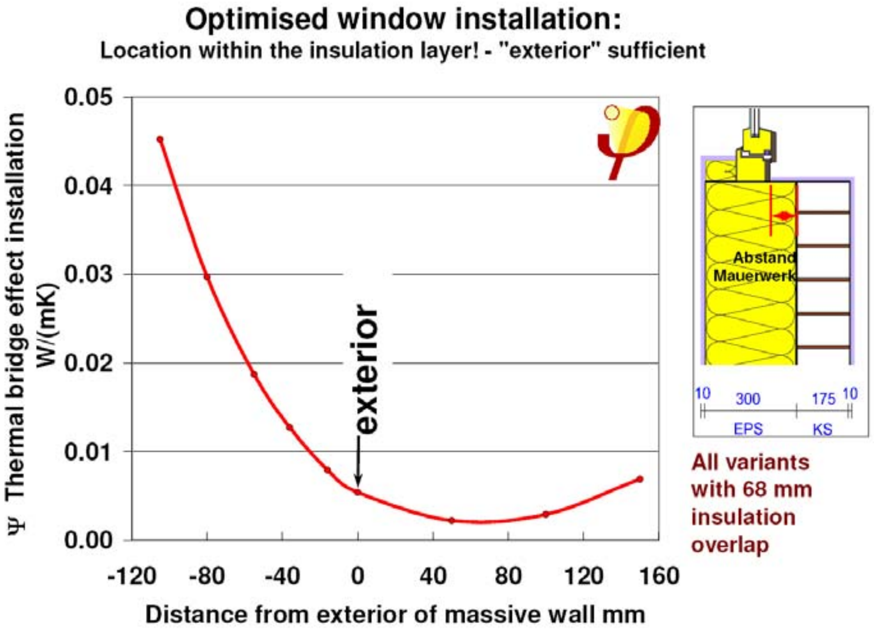


Figure 3.4-36
Window installation
Thermal bridge effect of installation position
[AKKP 14] [AKKP 37]

Window installation 2.2

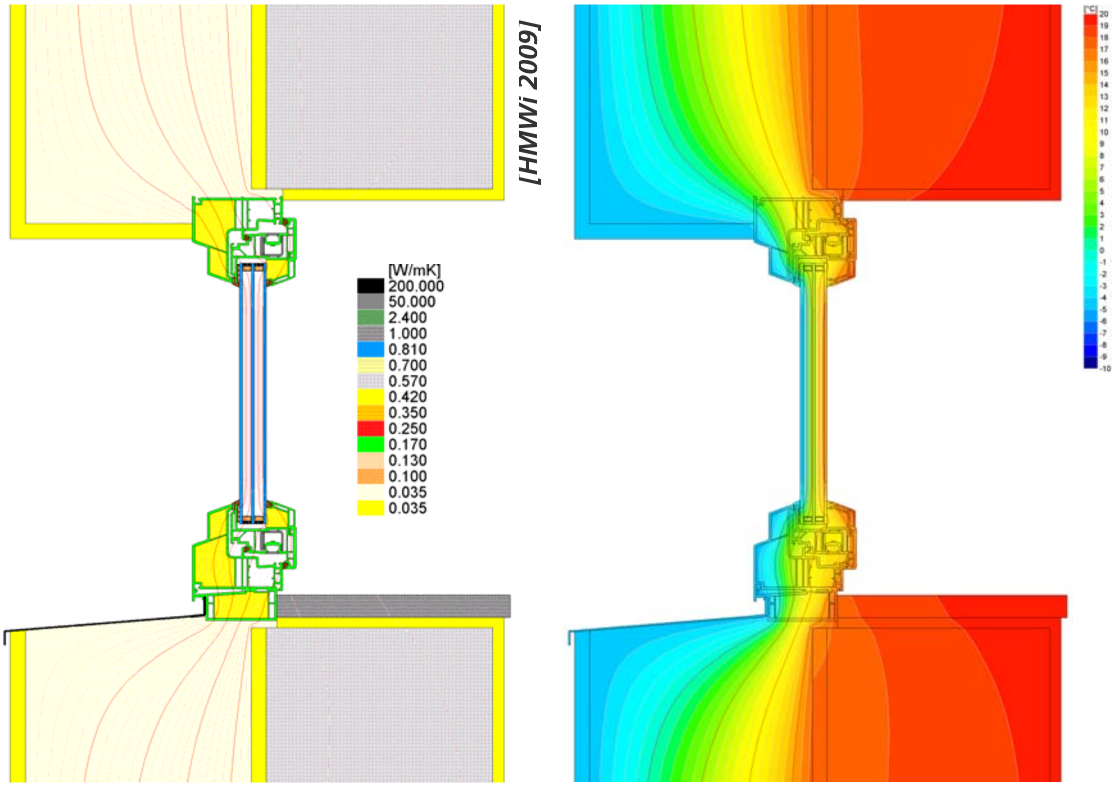


Figure 3.4-37
Materials/isotherm image

Temperatures image
Frame installed partially within reveal, where possible integrated in exterior wall insulation.
Boundary conditions:
Exterior wall U = 0,107 W/(m²K)
300 mm 0,035 W/(mK)
Resulting thermal bridge effect:
$\Psi_{fixture}$ *(top/lateral) = 0,015 W/(mK)*
$\Psi_{fixture}$ *(bottom) = 0,053 W/(mK)*
mean: $\Psi_{fixture}$ *= 0,024 W/(m²K)*
U_W *= 0,86 W/(m²K)*
T_{min} *= 15,1 °C*

Window installation 2.3

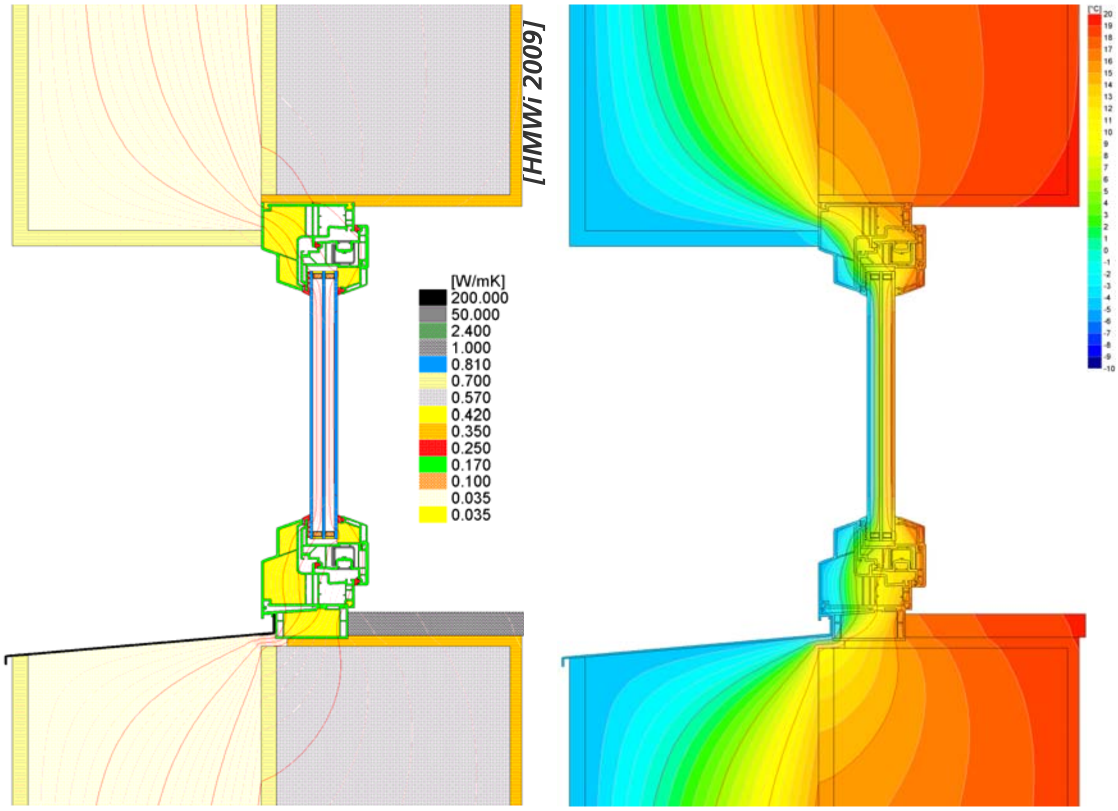


Figure 3.4-38
Materials/isotherm image

Temperatures image
Frame installed entirely within reveal, where possible covered by exterior wall insulation.
Boundary conditions:
Exterior wall U = 0,107 W/(m²K)
300 mm 0,035 W/(mK)
Resulting thermal bridge effect:
$\Psi_{fixture}$ *(top/lateral) = 0,050 W/(mK)*
$\Psi_{fixture}$ *(bottom) = 0,129 W/(mK)*
mean: $\Psi_{fixture}$ *= 0,068 W/(m²K)*

U_W *= 0,99 W/(m²K)*
T_{min} *= 15,1 °C*

3.4.5 Window Installation, practical issues

From a practical point of view window installation has to be as easy and fast as possible. On the other hand, the extra weight of three pane glazing is not to be neglected even for typical dimensions of windows (1.25 m x 1.5 m).

There are several systems available for the fixation of window frames outside the old masonry wall. The most simple is shown in Figure 3.4-39 ff.

The idea is to fix a wooden timber beam right below where later the window is. This beam may be levelled easily and fixed. Afterwards the heavy window elements may be released there and fixed at the sides with steel angles.

The effect of the wooden bar to the ψ-value is not zero but it is acceptable, see the several examples.

If the bar might get into contact with water (not intended but possible for balcony doors) polyurethane recycling material may be used instead of wood, as this is resistive against humidity.

Exchange of windows

Figure 3.4-39
Window-opening with masonry-rabbets removed

A piece of timber facilitates fixture of windows: It is installed and levelled in advance and later on bears the window's weight. The window is then fixed with stainless steel angles.

Top and lateral parts should be covered with the exterior wall insulation as far as possible.

Window installation 3.1

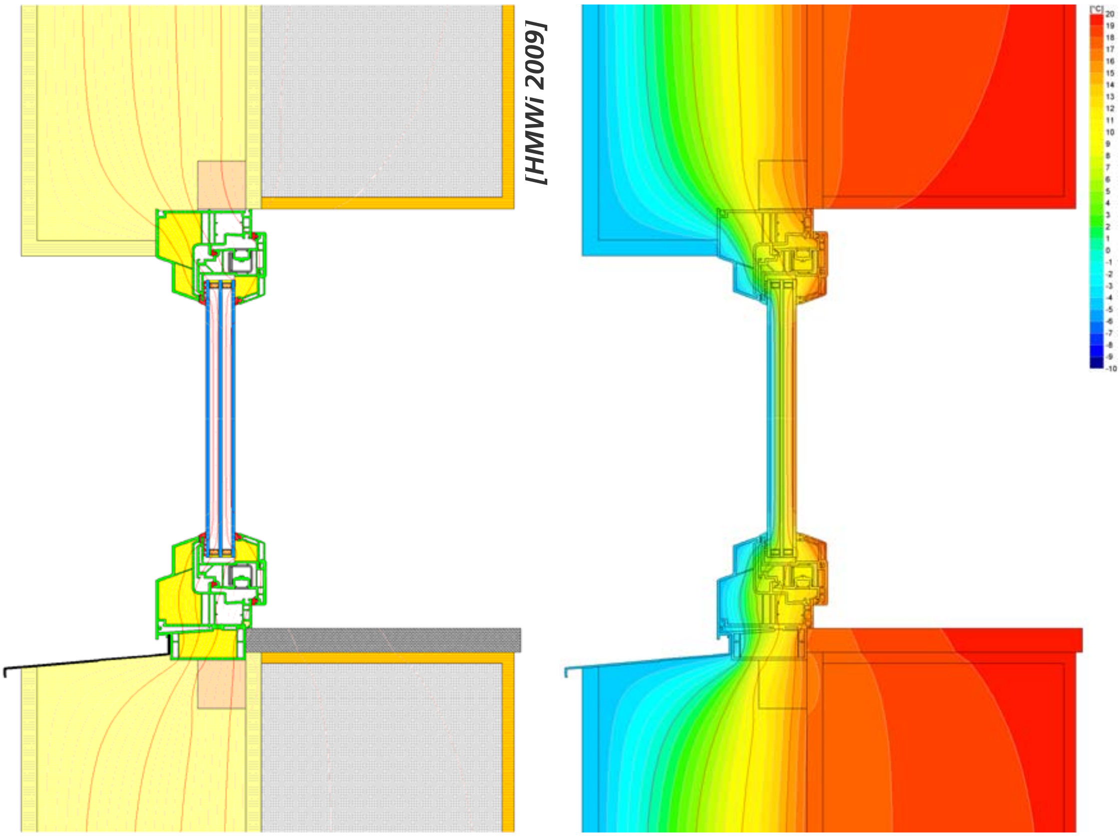


Figure 3.4-40
Materials/isotherm image (left)
Temperatures image (right)
Frame installed on outer surface of exterior wall, where possible covered by exterior wall insulation. An auxiliary frame of timber is used to ease fixture.
Boundary conditions:
Exterior wall U = 0,122 W/(m²K)
260 mm 0,035 W/(mK)

Resulting thermal bridge effect:
$\Psi_{fixture}$ (top/lateral) = 0,014 W/(mK)
$\Psi_{fixture}$ (bottom) = 0,050 W/(mK)
mean: $\Psi_{fixture}$ = 0,022 W/(m²K)
U_W = 0,85 W/(m²K)
T_{min} = 15,1 °C

Window installation 3.2

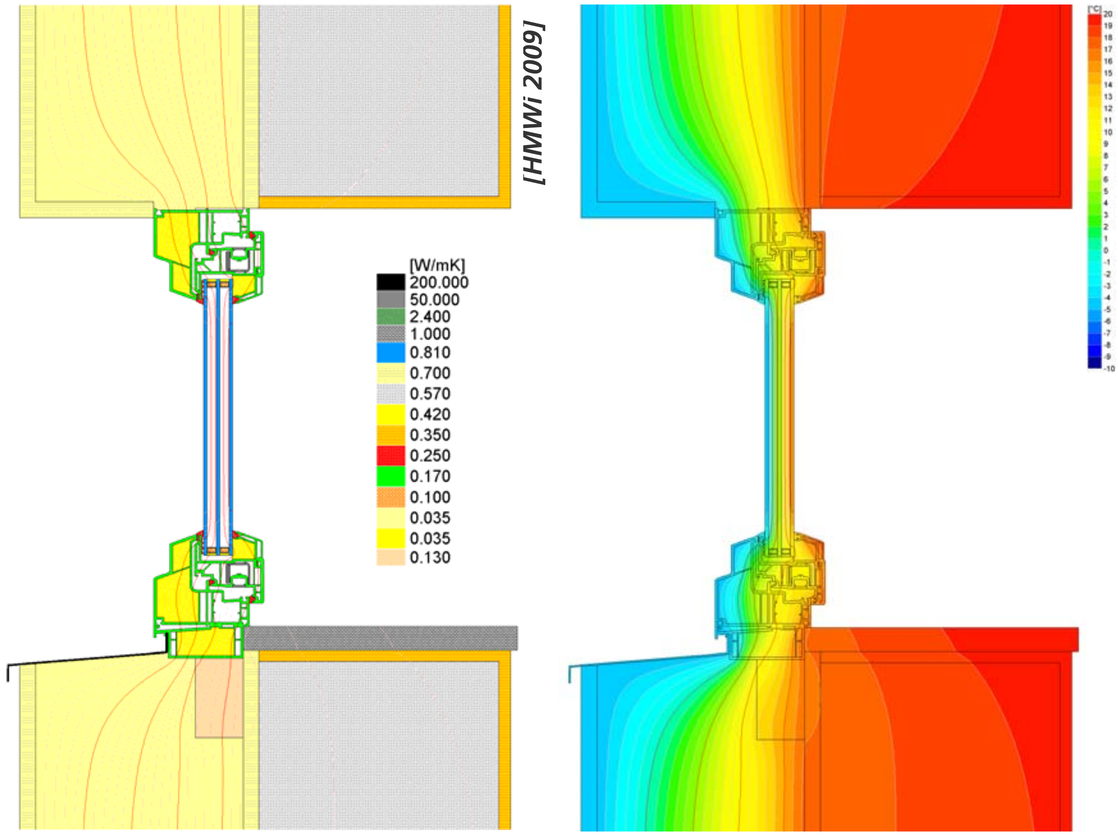


Figure 3.4-41
Materials/isotherm image

Temperatures image
Frame installed on outer surface of exterior wall, where possible covered by exterior wall insulation. An auxiliary piece of timber 6/10 cm at the bottom is used to ease fixture.
Boundary conditions:
Exterior wall U = 0,122 W/(m²K)
260 mm 0,035 W/(mK)
Resulting thermal bridge effect:
$\Psi_{fixture}$ (top/lateral) = 0,016 W/(mK)
$\Psi_{fixture}$ (bottom) = 0,053 W/(mK)
mean: $\Psi_{fixture}$ = 0,024 W/(m²K)

U_W = 0,86 W/(m²K)
T_{min} = 15,1 °C

Window installation 3.2a

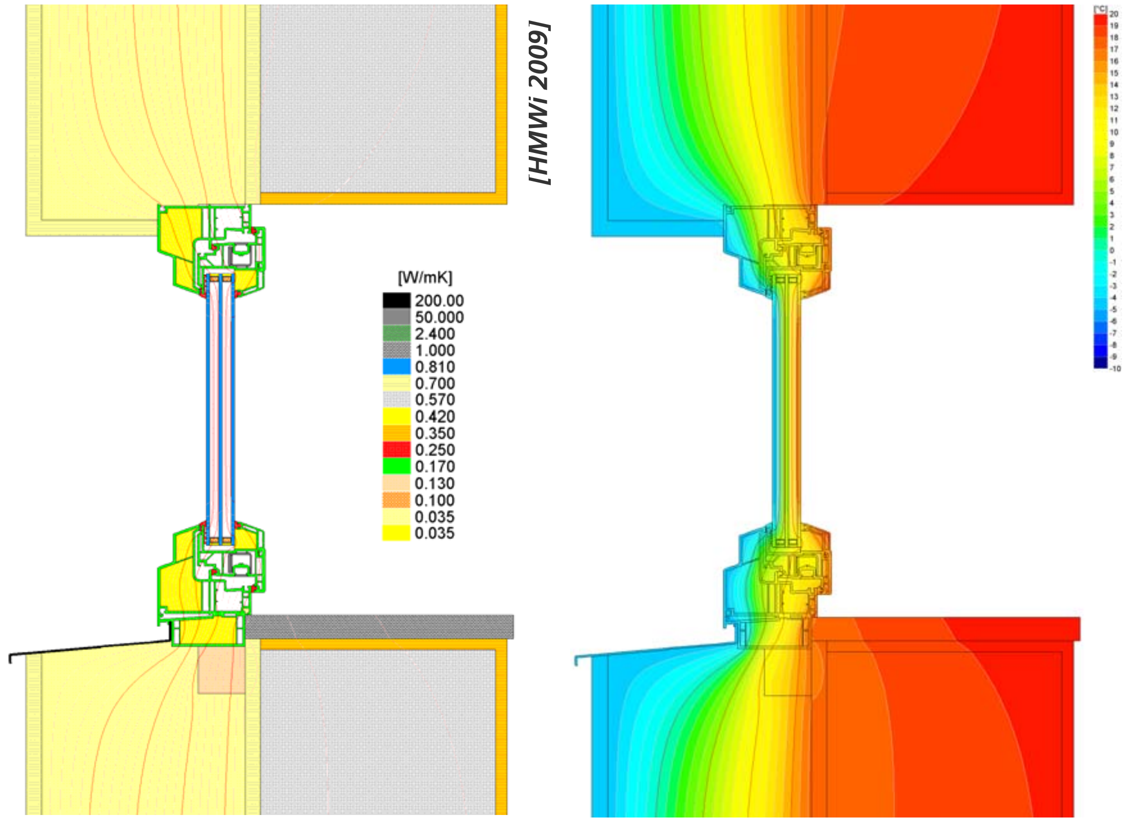


Figure 3.4-42
Materials/isotherm image (left)
Temperatures image (right)
Frame installed on outer surface of exterior wall, where possible covered by exterior wall insulation. An auxiliary piece of timber 6/6 cm at the bottom is used to ease fixture.
Boundary conditions:
Exterior wall U = 0,122 W/(m²K)
260 mm 0,035 W/(mK)

Resulting thermal bridge effect:
Ψfixture (top/lateral) = 0,011 W/(mK)
Ψfixture (bottom) = 0,050 W/(mK)
mean: Ψfixture = 0,020 W/(m²K)

UW = 0,85 W/(m²K)
Tmin = 15,1 °C

3.4.6 Windows with additional roller shutters

To install additional roller shutter the window frame may be too slim and therefore need to be widened by an extra profile. Conventional plastic add-on profiles are normally not filled with insulation as it is the case for the chambers of well insulated window frame profiles. This might partially be accepted as shown in Figure 3.4-43, but the rule is, that a minimum insulation layer thickness must be provided to avoid condensation on any inner surfaces.

The solutions shown in Figure 3.4-43 ff provide a polyurethane element with about 50 mm thickness in addition with a standard frame-add-on-profile. Newer solutions provide ready to use insulated profiles.

The same is the case for the right and left railing, of roller shutters. In conventional configuration, the railing of the shutter on right and left reveal is in conflict with the overlap of insulation. Insulated extra profiles as add-on to the frame profile with rails for the shutter are meanwhile available for some frame systems.

Meanwhile (2010) solutions for boxes of roller shutters are available which are fully insulated because the whole case is made out of polystyrene or poly urethane.

See the following graphs and corresponding ψ-values to evaluate the effect of roller shutters on the energy balance of a building.

Please note: roller shutters are normally not able to reduce the U-value of a window when closed. The reason for that is that conventional shutters are not insulated and – what is more – the shutter is not fully airtight at the lower end, when closed. The airtight sealing of the gap between shutter and window would be absolutely necessary to provide an effect on the overall U-value of the window.

Window installation 4.1

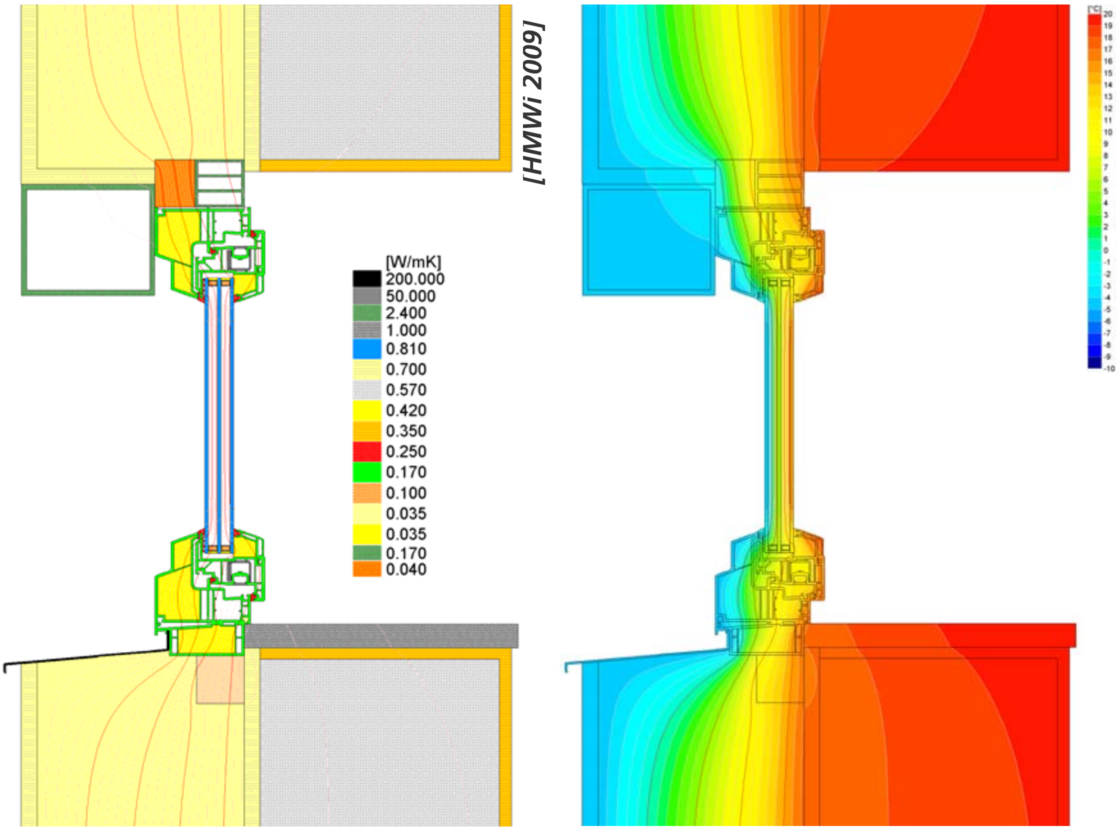


Figure 3.4-43
Materials/isotherm image

Temperatures image
Frame installed on outer surface of exterior wall, where possible covered by exterior wall insulation. To enlarge clearance at the top for an exterior rolling shutter a frame extension combined with an insulation panel is added.

Boundary conditions:

Exterior wall U = 0,122 W/(m²K)

260 mm 0,035 W/(mK)

Resulting thermal bridge effect:

$\Psi_{fixture}$ (top) = 0,040 W/(mK)

$\Psi_{fixture}$ (lateral) = 0,016 W/(mK)

$\Psi_{fixture}$ (bottom) = 0,050 W/(mK)

mean: $\Psi_{fixture}$ = 0,043 W/(m²K)

U_W = 0,91 W/(m²K)

T_{min} = 15,1 °C

Window installation 4.2

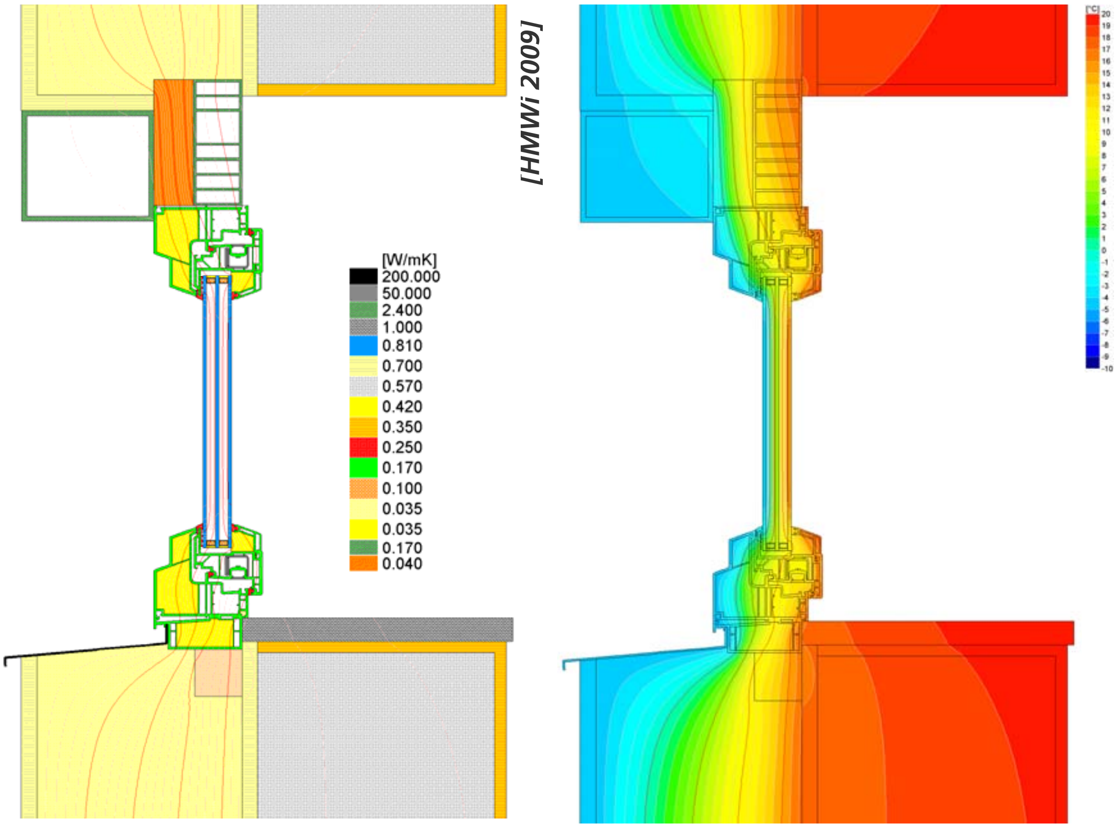


Figure 3.4-44
Materials/isotherm image

Temperatures image

Frame installed on outer surface of exterior wall, where possible covered by exterior wall insulation. To further enlarge clearance at the top for an exterior rolling shutter a larger frame extension combined with an insulation panel is added.

Boundary conditions:

Exterior wall U = 0,122 W/(m²K)

260 mm 0,035 W/(mK)

Resulting thermal bridge effect:

Ψfixture (top) = 0,080 W/(mK)

Ψfixture (lateral) = 0,016 W/(mK)

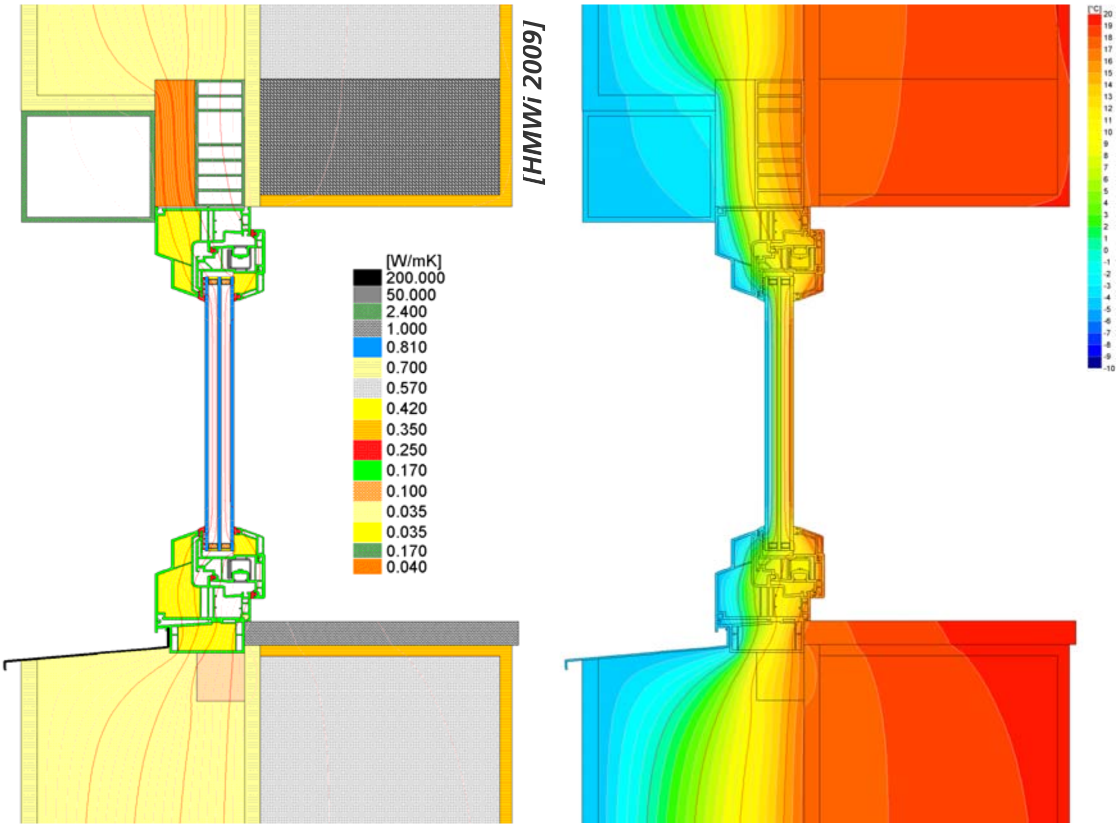
Ψfixture (bottom) = 0,050 W/(mK)

mean: Ψfixture = 0,050 W/(m²K)

UW = 1,01 W/(m²K)

Tmin = 15,1 °C

Window installation 4.3



[HMWi 2009]

Figure 3.4-45
Materials/isotherm image

Temperatures image

Frame installed on outer surface of exterior wall, where possible covered by exterior wall insulation. Frame extension covers new concrete lintel.

Boundary conditions:

Exterior wall U = 0,122 W/(m²K)
260 mm 0,035 W/(mK)

Resulting thermal bridge effect:
$\Psi_{fixture}$ *(top) = 0,077 W/(mK)*
$\Psi_{fixture}$ *(lateral) = 0,016 W/(mK)*
$\Psi_{fixture}$ *(bottom) = 0,050 W/(mK)*
mean: $\Psi_{fixture}$ *= 0,071 W/(m²K)*

U_W *= 1,00 W/(m²K)*
T_{min} *= 15,1 °C*

3.4.7 Anchors to fix standalone balconies

In many renovation projects, there are new balconies added where no balconies were present before, to provide better living comfort. On the other hand many old balconies out of the 1960ies and 1970ies would lead to heavy thermal bridge effects, because of the concrete penetrating the later insulation layer.

So in many renovation projects, there have been made good experiences with added standalone balconies. These have to be fixed to the building against wind loads, but these fixings may be rather slim, and therefore the additional thermal bridge effects remain small. The example of Figure 3.4-46 ff show a solution with simple steel angles fixed to the wall. The penetration through insulation layer is rather slim. So the thermal bridge effect of each anchor turns out to be λ = 0,090W/K only. The minimum surface temperatures inside are always > 18 °C.

Figure 3.4-46
Stainless balcony tie: anchoring channel on 10mm stainless cantilever bolted through exterior wall with interior conterpiece.

Balcony anchor diligently integrated in exterior wall insulation (260 mm 0,035 W/(mK))

[HMWi 2009]

Balcony anchors - results

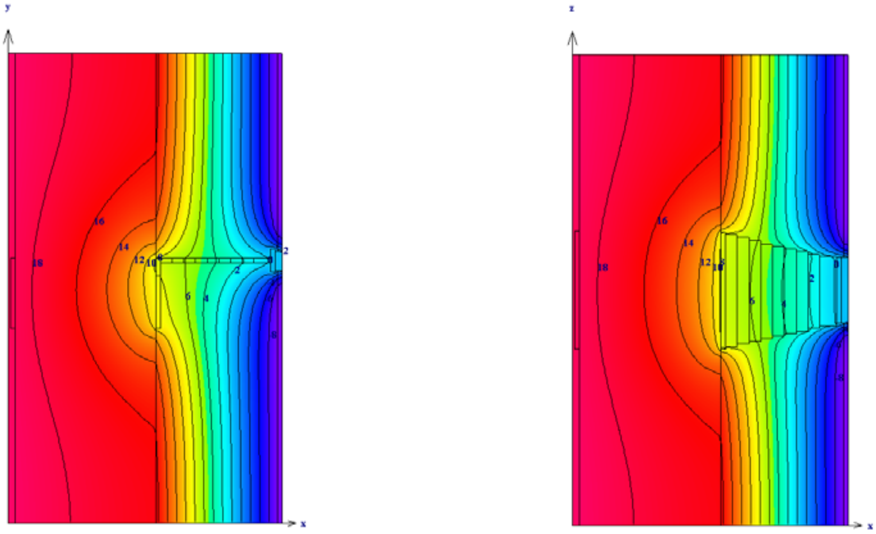


Figure 3.4-47
Balcony anchor temperatures image, vertical section

Balcony anchor temperatures image, horizontal section

Boundary conditions:

Exterior wall U = 0,122 $W/(m^2K)$

260 mm 0,035 W/(mK)

stainless steel λ = 17 W/(mK

Resulting thermal bridge effect:

χ = 0,090W/K

T_{min} = 18 °C

[HMWi 2009]

Balcony anchors – model for thermal flux calculation

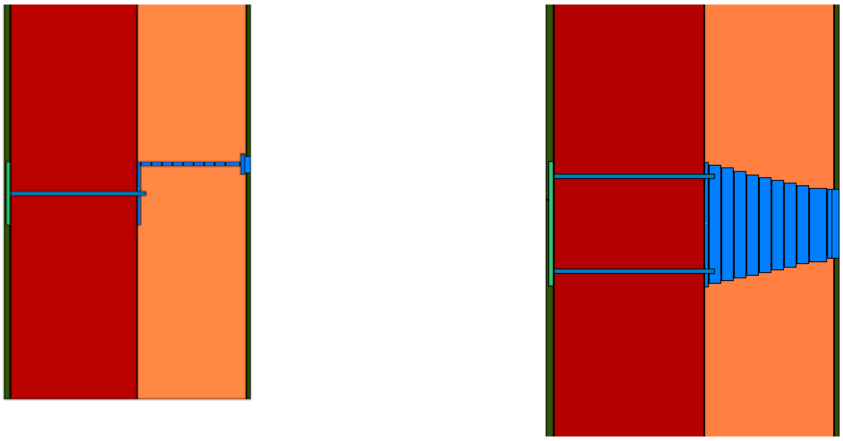


Figure 3.4-48
Balcony anchor 3D model, vertical section

Balcony anchor 3D model, horizontal section

[HMWi 2009]

3.4.8 Interior Insulation

A standard task in highly efficient renovation projects is to improve the thermal quality of the building shell. Usually this goal is reached by adding an insulation layer on the exterior of the façade. This offers threefold advantage:

- No living space is lost. Insulation thickness may be chosen to suit the precise needs of the project.
- Exterior insulation is uncritical in terms of building physics
- No thermal bridges occur systematically (except for balconies and base)

Moreover exterior insulation may be applied without interfering with inhabitants. Realised projects show that using highly efficient components an increase in efficiency by a factor of 10 is possible and economic.

Yet there are cases where exterior insulation is either not possible or excluded by other claims. Common situations encountered are e.g. listed buildings with valuable facades or buildings directly on property lines. In those cases interior insulation together with highly efficient components is a way to improve the building's energy efficiency by a factor of four. Some systematic disadvantages have to be handled though:

- Loss of living space limits insulation thickness
- Thermal bridge effects of inner walls and ceilings reduce the overall thermal performance significantly
- Thorough planning is required to ensure damage-free function
- Precise execution and on-site quality insurance are indispensable

To account for the loss of living space insulation thickness is reasonable within the range of 80-100 mm. Materials with very low thermal conductivity allow for better U-values but simultaneously the impact of thermal bridges rises. The most critical complex is moisture protection from the outside as well as from the inside. As elsewhere thermal bridges lead to both heat loss and low surface temperatures with threat of moisture accumulation and mould. Thermal bridge effect may be limited and surface temperatures raised by adding escorting insulation on the first metre of interior walls or ceilings/floors.

As a real prerequisite of interior insulation any exterior sources of moisture such as rising moisture from the foundations or driving rain must be reliably cut off. Ex-post installation of horizontal moisture barriers and water-repelling yet vapour permeable treatment of façade surfaces are special topics and must be planned diligently. Most insulation materials are vapour permeable. Therefore in most cases a vapour barrier/retarder is needed on the inside to prevent condensation in the colder regions towards the interior of the old massive wall. To realise a functional vapour barrier with the known constraints of a construction site is a challenging task. Precise planning and diligent execution under intense supervision is inevitable. Especially penetrations e.g. by wooden beams of the floor and joints along interior walls need reliable detail solutions. For this reason it is strongly recommended to avoid any installations in exterior walls with interior insulation.

As the quality of the vapour barrier is critical for the interior insulation it needs to be protected during the useful life of the wall. Penetrations by nails, screws and other impacts need to be inhibited. The windows represent the insulation layer within façade openings. Just as in buildings with exterior insulation they should be installed within the insulating layer without any offset to avoid a thermal bridge. This implicates windows to be installed very deep in the soffit. Yet in historical/listed buildings the window position is already set and cannot be altered. It is then possible to both keep the old window completely for looks and weather protection and add a thermally qualified new window from inside where it can be installed right within the insulating layer can be easily connected to the vapour barrier for air tightness. Or to replace the old window in its original position and add soffit insulation (all around) to connect the (offset!) insulation layers. A considerable thermal bridge effect has to be taken into account but surface temperatures can be raised to a safe level.

To achieve good thermal comfort close to windows and to make use of the energy saving potential it is advisable to fit triple-pane glazing and insulated frames (Passive House components). Given this situation a radiator underneath the window is not required a new radiator may be installed anywhere in the room which allows for optimised and cost efficient pipe work.

A promising new technique for interior insulation is using cellulose fibre insulation material. The material can be applied in a wet spray-on process with little labour cost and on very uneven surfaces. It can be used to create a new interior plane and thus solve two problems in one process. Once the cellulose layer is dried and hardened (after about for weeks, depending on climate conditions) it can be plastered using a specially developed cement plaster. The plaster also serves as the airtight layer consequently all joints of plaster and windows or plaster and penetrating beams etc. must be well detailed.

Cellulose is a **capillary active** material which means that liquid water can be transported in capillary tubes of the fibrous material. Given air tightness of the plaster and thus no convective transport of moisture there is only diffusion carrying vapour through the insulation assembly. A small amount of condensate is generated in the outer part of the cellulose layer. The important advantage is the capillary active behaviour of the cellulose material that transports moisture in the opposite direction of the diffusion flow back towards the warm interior surface. There it may evaporate and the cycle begins again. The described mechanism even gives a certain tolerance to minor production faults or damages. The material has been surveyed in laboratory conditions, numerical simulation and first on-site monitoring programmes that proved the basic function of the assembly. A new monitoring is carried out within this task to further investigate the material’s properties and especially its behaviour as soffit insulation.

3.4.9 References

[58] [ISO 7730] DIN EN ISO 7730-1995-09 Moderate thermal environments -- Determination of the PMV and PPD indices and specification of the conditions for thermal comfort
The standard presents a method for predicting the thermal sensation and the degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments and to specify acceptable environmental conditions for comfort.

[59] [AkkP 24] Einsatz von Passivhaustechnologien bei der Altbaumodernisierung Protokollband 24 des Arbeitskreises kostengünstige Passivhäuser, Dr. W. Feist (Hg.), Darmstadt 2003
Detailed analysis of highly efficient renovation using Passive House technologies featuring the showcase example “Jean-Paul-Platz” in Nuremberg.

[60] [EN 13829] EN 13829:2001 Thermal performance of buildings. Determination of air permeability of buildings. Fan pressurization method.

[61] [IBO 2008] Details for Passive Houses, Austrian Institute for Healthy and Ecological Building (Ed.), Vienna 2008
The book features plenty of information from basic knowledge in energy efficient construction to a variety of construction details. Though aiming at new construction many of the details can also be helpful in renovations. Thermal bridge coefficient and an ecological rating of every detail is included.

[62] [PHPP 2007]Passive House Planning Package, Passivhaus Institut Dr. W. Feist, Darmstadt 2007
The Passive House Planning Package (PHPP) is a clearly structured design tool that can be used directly by architects and designers. Detailed energy balances can be calculated and used to optimize the enegy efficiency of buildings in new construction as well as in renovation.

[63] [passipedia] The Passive House Resource: basic information about ventilation systems, www.passipedia.org

[64] [HMWi 2009] Feist, Kaufmann, Pfluger, Peper, Grove-Smith, Sanierung mit Passivhauskomponenten – Planungsbegleitende Beratung und Qualitätssicherung, Tevesstraße Frankfurt a.M. Renovation Project Frankfurt Tevesstraße, Darmstadt 2009. The full project documentations are available for download at www.passiv.de.

[65] [Zellulose-Innendämmung] Zellulose-Innendämmung ohne Dampfsperre Berichte aus Energie- und Umweltforschung 84/2006, Bundesministerium für Verkehr, Innovation und Technologie (Ed.), Vienna 2006

[66] [Hasper 2010] Wolfgang Hasper, Internal insulation with sprayed cellulose fibre. Research report in the framework of IEA Task 37 Passive House Institute, Darmstadt, 2010

3.5 New technologies

3.5.1 Sprayed-on and trowel-applied internal cellulose insulation without vapour barrier

Herwig Hengsberger, Peter Kautsch, Rudolf Plagge, Andreas Heinz, Hans Petzold, Wolfgang Lackner, Robert Schmied, Peter Häupl, Wolfgang Streicher, Friedrich Skofitsch

Introduction

Thermal renovation of buildings with a low thermal standard is the most efficient way to reduce CO_2 emissions in relation to investment costs. In the past, thermal renovation of existing inner-city, in some cases listed, buildings by means of external insulation involved a great deal of time and work, if it was possible at all in view of complicated ownership situations, structured façade geometries, or because established building lines had already been reached. Although it hardly seems realistic to try to achieve Scandinavian insulation standards, for example, in old buildings, internal insulation can help reduce the U-value of existing outside walls by as much as 50%.

Because the ecological quality of the building materials used will need to be given greater attention in future, the aim of a research project under the “Haus der Zukunft” (Building of Tomorrow) programme 0 subsidised by the Austrian Federal Ministry of Transport, Innovation and Technology was to examine sprayed-on and trowel-applied layers of cellulose insulation made from recovered paper with regard to their suitability as internal insulation without a vapour barrier both in terms of mechanical performance and building physics [79]. Cellulose insulation materials can make a valuable contribution to ecologising the insulation material market because, being a recycling product, they are manufactured on the basis of the renewable resource wood. As a practically CO_2 -neutral insulation material with an extremely low primary energy demand, cellulose insulation can also be attributed a particularly positive environmental relevance.

What is more, because of its excellent moisture-retaining properties combined with the high capillary conductivity of the bound cellulose flakes, in certain circumstances it is possible to do without a vapour barrier, which often tends to be fault-prone. This can increase the acceptance of internal insulation measures quite considerably in building practice.

In addition, there has recently been a growing demand for insulation materials for historic buildings that preserve the original character of the surface. The sprayed-on cellulose insulation system covered with thick plaster responds very well to this trend.

Methodology

Following extensive laboratory experiments for developing and optimising the sprayed-on cellulose layer and the special internal plaster, the insulation system was assessed by means of in situ measurement of hygrothermal conditions across the full cross-section of the structural element in real climate conditions over duration of two condensation and two evaporation periods. The extensive data collected regarding the characteristic material values of the internal plaster and the bound cellulose insulation and integration of these data to draw up complex moisture-retention and transport functions served as a basis for the accompanying hygrothermal simulation calculations using the DELPHIN software package [68] and to validate the mathematical model with regard to the innovative building materials. This created a basis for a preliminary calculative estimation of future renewal measures.

Procedure

The innovative insulation system consists of defibrated recovered paper with an admixed flame-retardant and fungicide component of borates and ammonium phosphate. By means of a newly developed conveyor machine, that does not transport the loose cellulose flakes in portions by means of a rotary feeder, as was previously the case, but rather continuously by means of a centrifugal fan, thus homogenising the flow of flakes, the material is delivered to a spray head, where it is moistened and, mixed with an acrylic-based

Figure 3.5-1
Spraying

polymer, sprayed onto almost any surface Figure 3.5-1 .

Then the cellulose layer is flattened with a rotating roller and covered with specially formulated internal plaster. This plaster should be a largely open-diffusion, moisture-retaining light-weight mineral plaster with a water vapour diffusion resistance μ-factor < 20 and a dry bulk density < 1200 kg/m³; it should be suitable for machining and should be applied to the cellulose insulation in one coat of 10 to 15 mm.

The combination of old masonry and new internal plaster (Figure 3.5-2) ensures that the system is air-tight in the plane. Although hair-line cracks in the internal plaster lead to slightly higher diffusion flows at the affected spots, these are buffered very well by the high capillary conductivity of the surrounding cellulose insulation. As with every internal insulation system, an air-tight seal to the window, inside walls or wooden beam ceilings is of particular importance. A current research project focuses specifically on incorporating wooden beam ceilings into a variety of open-diffusion internal insulation systems [80].

As a basis for the building physics simulation calculations, following numerous steps to optimise the final plaster formulation, moisture sorption in the hygroscopic range based on ISO DIS 12571 [76] and in the superhygroscopic range based on ISO DIS 11274 [75] (sorption isotherm and water retention) and drying characteristics were determined in addition to standard parameters such as water demand, air pore content, water retention capacity, fresh mortar bulk density, solidification behaviour, strength development, flexural and compressive strength, total and open porosity, modulus of elasticity, water absorption coefficient (based on EN ISO 15148 [73]), hydraulic conductivity (based on ISO/CD 17312 [76] and 17313 [78]), water vapour diffusion resistance factor μ (dry-cup, based on EN ISO 12572 [72]), thermal conductivity, heat capacity and dry bulk density.

The characteristic material values measured at Dresden University of Technology were prepared for direct use in the simulation models that require continuously differentiable and integrable functions instead of numerical data. The characteristic values were functionalised with the aid of a physical material model, mapping water retention characteristics, liquid water conductivity, water vapour diffusion resistance, and thermal conductivity as functions.

Figure 3.5-2
Cross-section of the insulation system

In order to validate the material measurements in the laboratory and the calculative functional adaptations, typical suction and evaporation experiments were recomputed with a physically based, scientific simulation program so as to adjust the function set and verify the material. The characteristic material values and hygrothermal functions were entered into a relational database system in which the material functions are visualised graphically in a clear, concise form and compared for easy selection.

In situ measurement

In order to measure and record the hygrothermal processes throughout the section of the wall, the system was covered with an on average 5 cm thick layer of cellulose on the west- and south-facing outside wall, consisting of 50 cm thick full-brick masonry plastered on both sides, of a roughly two-hundred-year-old building in Graz. Both the insulated and an un-insulated control wall section were equipped with numerous sensors.

In addition to global radiation and heat flow in the insulated and un-insulated area, this involved measuring the temperature and moisture content of the outside and inside room air and typical cross-sections in the middle of the wall, in the inside edge of the outside corner, and in the area where the inside wall abuts the inside-insulated outside wall for a duration of two condensation and two drying periods Figure 3.5-3. In order to determine the moisture content of the structural element, the relative humidity of the air enclosed in the structural element and in

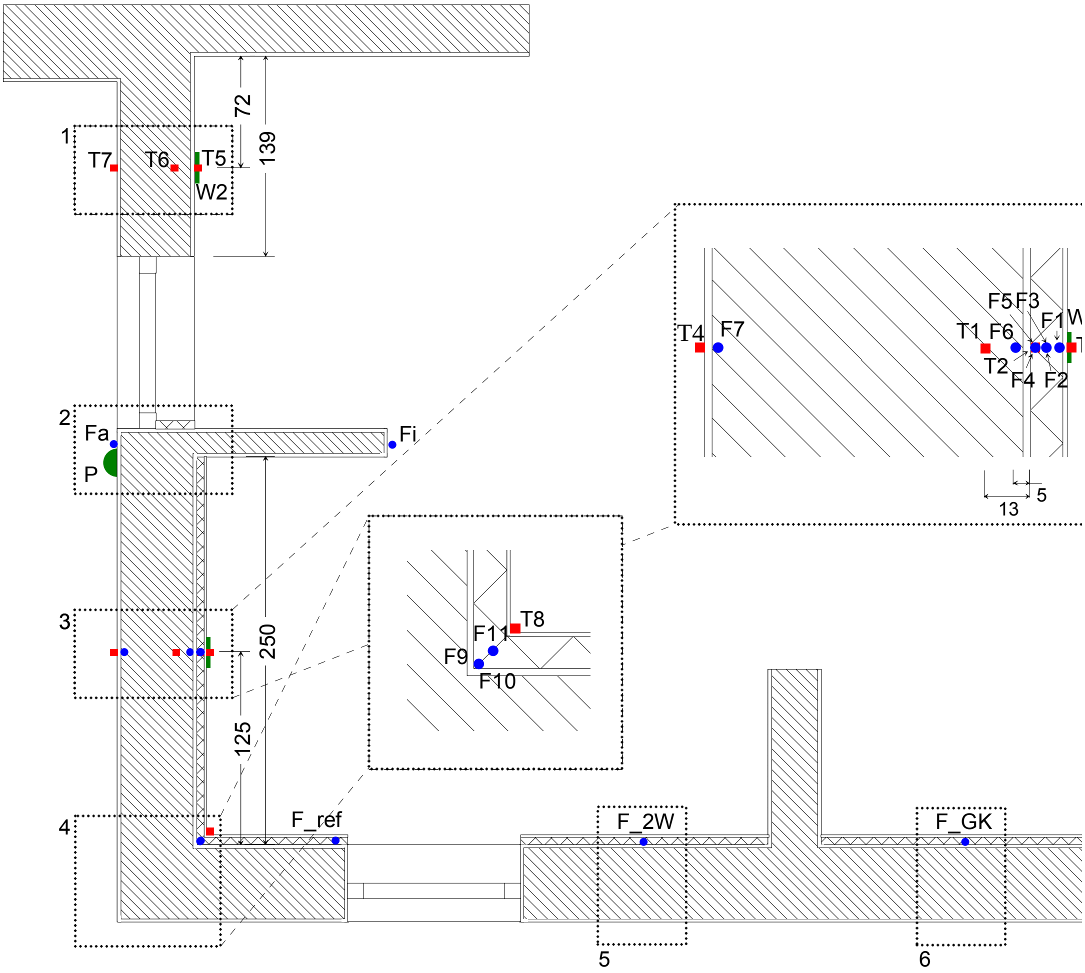


Figure 3.5-3
Floor plan of the trial room with sensors (double sensors at sensitive points)

F … Combined temperature/moisture sensor

T … Pt100 sensor (temperature)

P …Pyranometer (irradiation)

W… Heat flow plate

the area of the specially developed, just 3 mm thin, salt-resistant sensors, i.e. equilibrium moisture content, was measured at hourly intervals.

On the basis of the sorption isotherms of the building material it is thus possible to calculate the absolute moisture content (water content) in the material and local dew point temperature.

Results

The measured data were continuously evaluated and incorporated into the simulation calculations. One particularly gratifying fact was that spraying did not impair the combined temperature/moisture sensors as they had been specially adapted for this purpose. Apart from the first condensation period, that coincided with the drying phase of the insulation system, all sensors returned plausible values, and it was observed that condensation dried up completely during the evaporation periods, there was no dreaded accumulation of moisture content over a period of several years.

Strength measurements

The aim of these analyses was not only to determine tensile strength perpendicular to the sample plane of the cellulose material itself, but also the adhesion bond with the base. For this purpose, the insulation material was sprayed onto 10 cm thick honeycomb bricks with which an un-mortared sample wall had been built. Once the cellulose layer had dried, it was separated along the brick joints and the layer of cellulose on the separate bricks was cut to a thickness of 4.5 cm parallel to the surface of the brick.

The measurements revealed strength values that exceed the requirements for mineral wool façade insulation boards to ÖNORM B 6135 [81] and the requirements for factory-made cellulose insulation boards to the ÖTZ specifications in accordance with OIB Directive [82] of ≥ 12.0 kPa in both cases.

The pull-off tests performed on the cellulose/plaster system sprayed in the trial house all revealed material fractures in the insulation layer, thus confirming the excellent adhesion bond of the innovative internal plaster with the cellulose base.

Hygrothermal simulation calculations

The Institute of Building Climatology at Dresden University of Technology developed an integrated physical model for coupled energy and material transfer in capillary-porous building materials. On the one hand, this model is implemented in the form of the numerical simulation package DELPHIN [68] and, on the other, finds expression in measuring regulations and measuring procedures above all for moisture-related material properties [74].

Unlike the "Glaser method", that allows measurement under simplified stationary conditions by calculating the maximum quantity of condensation in relation to the amount of drying during the warm season, but which fails to account for moisture retention and moisture conductivity of building materials, the DELPHIN simulation tool can be used to simulate heat and moisture retention as well as moisture transport under non-stationary conditions. All humidity retention and conversion processes are included; boundary conditions may be model-based constant boundary conditions or any non-stationary climate boundary conditions. As such, it is possible to expose a structure to a range of outdoor climate conditions (including rain, short- and long-wave radiation exchange) or to examine the influence of different user-dependent indoor climates, including those measured in situ.

In order to model real processes, moisture conductivity and the moisture retention function are important building blocks; the latter describes retention of moisture in capillary-porous materials as dependent on relative humidity (in the pores) and capillary pressure, and the analysis of super-hygroscopic properties is of particular relevance in assessing the quantity of condensation that builds up and in estimating the time that condensation takes to dry [83].

The moisture retention function is determined by means of pressure plate and sorption measurements. An additional determination of moisture retention can also be performed – with the aid of a suitable pore model – by means of a pore structure analysis (mercury intrusion porosimetry, nitrogen BET and optical methods). Finally, capillary hydraulic conductivity is derived from the pore structure and the measurement of the water sorption coefficient (Aw value) and water resistance in the free saturation range.

As a result of the low thermal conductivity of 0.052 W/mK, despite the considerable density of 92 kg/m³, the bound cellulose is very well-suited as an insulation material.

As expected, vapour diffusion resistance μ (dry-cup) is relatively low, approximately 2.5 [-]. The measurements also revealed surprisingly high liquid water conductivity. This means that condensation that builds up as a result of internal insulation can be removed by capillary action.

The porous internal plaster formulated specially for the sprayed-on cellulose has a relatively low water vapour diffusion resistance factor (μ) of approximately 6 [-]. The cellulose/plaster system is thus a capillary-active and open-diffusion internal insulation system.

Once the measurements of outdoor and indoor climate for the trial house and measurements on and inside the structure had been obtained, the simulation calculations were continuously compared with the measured values. The measured climate values were used as non-stationary boundary conditions for the simulation, from which the state values in the structure were derived. The parameters defined in the laboratory were used for the materials.

The comparison of temperatures in the middle of the insulation shows a very good agreement. Humidity in the measurement is slightly higher than the calculated values and show higher amplitudes, although the deviations of around 5 % relative humidity are within an acceptable range. The cause of this effect is assumed to be that humidity measurements are performed in a small air space, while the simulation represents the conditions in the material itself.

Because of the generally good agreement between the measurements and calculations, it was possible to use other variables from the simulation calculations that cannot be measured directly, such as moisture mass in the structure and moisture profile, in order to assess the behaviour of the structure. In the real indoor and outdoor climate conditions in the trial house, the moisture profiles displayed a max. moisture content of just over 5 vol.% in one- and two-dimensional calculations.

Both in the wall and edge area, humidity of more than 80 % occur over a prolonged period during the cold period. Temperatures are relatively low, however, with the effect that these humidity values do not entail such a high risk of mould as when the 80 % limit is reached on room-facing surfaces exposed to spores. Light-microscopy analysis of samples from the trial house did not reveal any mould growth. Although the DIN 4108-equivalent analysis [69] with a constant climate indicates condensation, at approximately 0.6 kg/m² it is still within the permissible range and can dry up completely.

The system of plaster and sprayed-on cellulose insulation can thus already be classified as positive in the undisturbed area of the wall from a hygrothermal point of view as the high capillary conductivity of the cellulose removes condensation by capillary action. Structural element joints such as wooden beam ceilings or window frames must be examined separately. Also, the findings can be transferred to other structures and other climates with the aid of the measured material functions and the hygrothermal simulation calculations.

Summary and prospects

By means of almost two years of in situ measurements it was possible to confirm the assumed excellent moisture transport and retention capacity of bound cellulose insulation. It was shown that the moisture that builds up during the condensation phase dries up completely during the evaporation phase – i.e. that the content of water in the insulation layer does not accumulate over a period of years. The innovative internal plaster formulated specially for the special plaster base has an extremely low water vapour resistance factor – an important pre-condition to assist the cellulose insulation drying process during the evaporation period. By combining these two new developments it was possible to create the prototype of an internal insulation system that in certain circumstances does away with the need for a vapour barrier thanks to special material properties. One extremely important result is the excellent agreement between the hygrothermal simulation calculations and the in situ measurements. Hence, with the aid of appropriate material parameters in future it will be possible to calculate and estimate the effects of these innovative internal insulation measures. The sprayed-on cellulose insulation meets the important tensile strength requirements perpendicular to the sample plane that must be fulfilled by external insulation and finishing systems, for example mineral wool insulation boards.

Figure 3.5-4
Apartment house in Fürth near Nuremberg thermally renovated with the new insulation system

Figure 3.5-5
Thermally renovated listed farmhouse with stone masonry in Kirchbichl / Tyrol

Figure 3.5-6
Interior before and after renovation (Kirchbichl /Tyrol)

The innovative internal insulation system presented here has already been practically tested on a number of pilot buildings, for instance an apartment building in Fürth near Nuremberg (Figure 3.5-4) or a 400-year-old listed farmhouse Figure 3.5-5 and Figure 3.5-6.

Although the homogeneity of flake transport was considerably improved by developing a completely new kind of conveyor machine, there is still a need for further research regarding the influence of different lengths and heights of conveyor tubing and with regard to differences in the spraying process.

A recently launched project subsidised by the Austrian Climate and Energy Fund examines the joints to wooden beam ceilings in comparison with other open-diffusion internal insulation systems available on the market and sets out to develop an innovative monitoring system for almost completely non-destructive analysis of any microbial growth.

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3.5.2 Vacuum insulation

Johann Reiss

Aiming to achieve building-envelope U-values smaller than 0.15 W/m²K by applying conventional insulation materials (like mineral wool, polystyrene, polyurethane rigid foam, cellular glass or cellulose), very thick layers of these insulation materials will be required. Meanwhile, however, some new insulation materials have become available, which are characterized by significantly lower thermal conductivities. These materials include vacuum insulation panels and aerogel. As shown in Figure 3.5-7, these insulation materials are distinguished by thermal conductivities ranging between 0.005 W/mK and 0.025 W/mK.

The principle of vacuum insulation has been known for a long time (by the example of the thermos flask, for instance). As early as in the 1970s, flat evacuated insulations were developed to be used in refrigerators and freezers. In the last few years, this technology was also introduced to the building sector. In 2001, Annex 39 entitled “High Performance Thermal Insulation“ [85], [86] was launched, which was concluded in 2005. Numerous investigations were performed in the scope of this research programme.

Principle, mode of action, application

As laid out in references [87], [88], [89] and [90] heat transfer in conventional and in evacuated insulation materials takes place by

- heat transfer through the solid skeleton λ_s,
- infrared radiative heat transfer λ_r
- heat conduction via the gas contained within the pores of the solid λ_g
- coupling term λ_c

In total, that is: $\lambda = \lambda_s + \lambda_r + \lambda_g + \lambda_c$,

With heat transfer being effected mainly by heat conduction through the gas contained in the pores, and by thermal conduction through the porous solid. Heat conduction in the solid linearly increases with thickness. Radiative transfer is inversely proportional to density. To achieve a reduction, radiation-absorbing opacifiers are added to the insulation.

Gaseous conductivity depends on the gas pressure or on the air pressure, respectively; it represents the largest contribution to heat transfer. This is related with the mean free path of the gas or air molecules. If one treats convection inside the pores as negligible (in the case of very small pores, convection tends to be zero), the ratio of gas conductivity: radiation: solid conductivity is 25 :13 : 2. To achieve a significant reduction in the heat transfer, the gas conductivity needs to be reduced. This can be accomplished by producing a vacuum. By choosing an insulation with a micro porous structure (pyrogenic silica with an added infrared opacifying agent, for instance) the ratio of gas conductivity : radiation : solid conductivity can be modified to a ratio of 0 : 1 : 3. Such materials are characterized by a heat conduction that is 10 times smaller than the heat conduction in conventional insulants. The principle is based on suppressing gas heat conduction by reducing the gas pressure in the volume that is to be evacuated. The pressure needs to be reduced to such an extent as to ensure that the gas molecules will no longer collide with each other, but only with the edges of the volume.

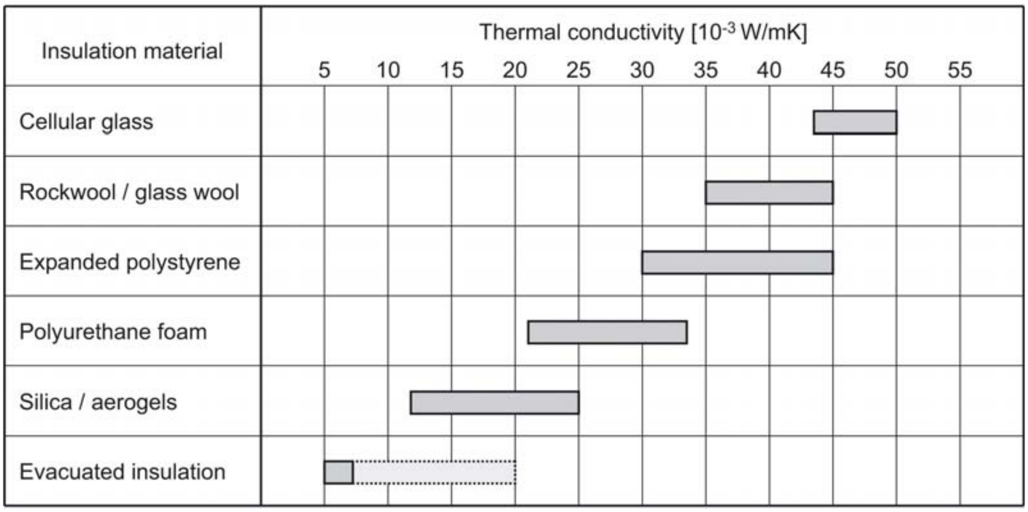


Figure 3.5-7
Thermal conductivity of various insulation materials

Vacuum insulation panels consist of a plate-shaped, high-porosity core material and a sufficiently tight envelope structure. These components cannot be cut to size like conventional insulation panels.

Core materials

Appropriate core materials are suitable for pressure loads and capable of being evacuated. They should be distinguished by a low thermal conductivity of the solid structure, a substantial reduction of heat radiation, and low gas conductivity up to a high level of residual gas pressure. The pressure load due to the atmospheric pressure is at 10^5 Pa. The graph in Figure 3.5-49 shows the thermal conductivity of various materials plotted against the gas pressure. Evidently, pyrogenic silica is suited best for a gas pressure of up to 100 mbar [91].

To keep the radiative heat transfer at a low level, opacifying agents need to be added to the basic powder. On account of their fine nanostructure, precipitated silica and pyrogenic silica are particularly suited for applications in thermal insulation panels.

At pressures of up to 10 mbar and at room temperature, the thermal conductivities are between 0.003 W/mK and 0.007 W/mK. Even in case of a technical failure of the insulating panel, the thermal conductivity of the material would still be about half as much as that of conventional insulation materials [88], simply due to its nanostructure.

Envelope materials

To ensure durability, the envelope material of an insulation panel should have the following properties [91]:

- high gas tightness
- high mechanical load capacity
- low thermal conductivity
- High dimensional and long-term stability.

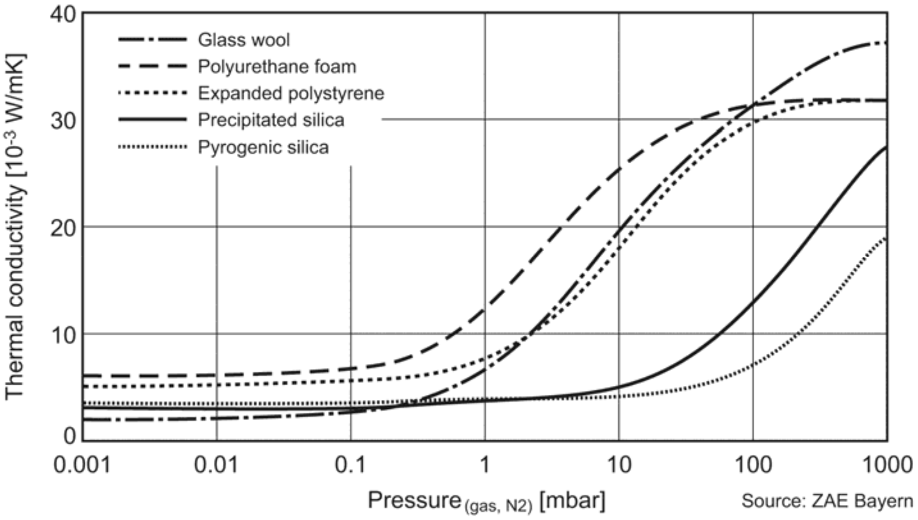
Suitable materials are sheet metal or metallic foils made of steel or stainless steel, aluminium composite films as well as multiple-layer aluminized plastic high-barrier laminates.

Although metal sheets are gas tight, the heat conduction through the panel edge is comparatively high. This is why such envelopes are only suitable for areas with a minimum size greater than 1m². As a rule, an aluminium composite film consists of an aluminium foil with a thickness of 6 to 12 micrometer to which plastic foils have been bonded on either side. Due to the high thermal conductivity of aluminium, however, the thermal bridge effect resulting at the edge is rather substantial.

Metalized high-barrier laminates proved to be suitable envelope materials. These laminates are multi-layered aluminized plastic foils. As the aluminium layer thickness is ranging in the nanometre scale, the heat conduction in the edge zone is found to be significantly lower than in the case of aluminium compound foils. The foils are connected by heat sealing.

Service life

The service life of a product is very important for applications in the building sector. A criterion for the service life is defined by exceedance of a specified gas pressure – like 100 mbar, for instance [93]. Considering the entire service life of a panel, the gas pressure inside the panel depends on the amount of the penetrating gases. According to references [85], [86] and [94] this process is affected by the operating conditions the panels are exposed to.



Source: ZAE Bayern

Figure 3.5-8
Thermal conductivity of infill materials as a function of gas pressure [92].

Table 3.5-1
Fire-protection requirements

Technical Requirements to Building Material Classes According to [96] and [97]

Technical requirement	Building material class DIN 4102-1	Euroclass DI EN 13501-1	Requirement level	Additional equirements, Notes
Non-flammable	A1	A1	No contribution to fire	-
	A2	A2	Negligible contribution to fire	Smoke production, burning droplets
Fire-retardant	B1	B	Very small contribution to fire	Smoke production, burning droplets
		C	Small contribution to fire	Smoke production, burning droplets
Normally flammable	B2	D	Acceptable contribution to fire	Smoke production, burning droplets
		E	Acceptable reaction to fire	Burning droplets
Easily flammable	B3	F	No requirements	Unsuitable for building

Transport and installation are particularly critical periods for vacuum insulation panels. Yet the risk of damaging can be reduced by careful and skilled handling. According to the technical approval documents it is required that only properly instructed and trained staff may be allowed to handle this material. Some manufacturers of vacuum insulation products protect the panels by adding layers of conventional insulating materials, which are bonded to both sides of the panel. However, this method has another disadvantage, namely the leanness of the insulation panels is affected.

The patented procedure va-Q-check (www.va-q-tec.com) allows measuring the internal gas pressure. In this way it is possible to check the correct function of the insulation panels. By performing several measurements in various time steps it is also possible to determine the service life. The measurement is based on the following principle: Below the envelope foil there is a metal sensor with a diameter of 30 mm. A specific excess-temperature is then applied to this spot by means of an external sensor. Based on the velocity of heat dissipation, the pressure inside the vacuum insulation panel can be indicated by means of a calibration curve [94].

Fire protection

Fire outbreak and flame spread depend on the flammability or combustibility of a building product [95]. Consequently, the materials have to comply with fire protection requirements according to [96] and [97].

The use of easily flammable construction materials is not allowed - with the exception of those materials, which (when installed) have at least standard flammability in conjunction with other products. When it comes to applying thermal insulation to façades of tower buildings and public institutions, only the use of non-flammable products is permitted.

The core material of the vacuum insulation is non-flammable and thus rated fire class A1. The foil enclosing the panel is easily flammable and therefore rated fire class B3. The entire panel is also rated fire class B3, but by bonding aluminium foil to the front and rear face of the panel requirements for fire class B2 are complied with. This panel may thus be used for building purposes. Covering the vacuum insulation panels with polystyrene foam allows them to be classified in fire class B1. The use of 'bare' vacuum insulation components for insulating façades is only allowed up to heights of 7 m. If the panels are totally covered in polystyrene, they may be applied in façade insulations of tower buildings up to < 22 m. It is recommended to closely examine the specific national or state fire-protection requirements prior to applying any insulation measure to the building.

Building authority approval

According to the manufacturers (Porextherm, Vaku-Isotherm, va-Q-tec, Microtherm) there are currently 15 different vacuum insulation products on the market, five of which have obtained a general technical approval from a building authority and may be used on building sites without furnishing any further proof of compliance. Those vacuum insulation products that are still waiting for their technical approval may also be used, however the approval for a specific case of application has to be granted. The building authority approval specifies the terms for the building product and the scope of application. [98]

Vacuum insulation in practical applications

Preferably, manufacturers or suppliers of vacuum insulation panels should become involved in the planning process at a very early stage. Likewise, owners and tenants need to be in-formed about the sensitive construction in order to prevent them from damaging the panels by drilling or nailing. Previous experience [99] has proved the functionality to last for five to ten decades.

Constructions involving vacuum insulation panels should be designed in such a way that the function of the whole construction will not be endangered by the failure of just one panel; likewise, the minimum thermal insulation as required in German standard DIN 4108 must not be endangered.

According to [100], vacuum insulation panels should be installed in a manner that enables their function to be checked during the entire life of the building and that allows panels to be easily replaced in case of failure.

As the vacuum insulation panels are vapour-tight, the layer sequence of a building component needs to be safe with regard to moisture problems. Joints and interruptions need to be permanently sealed and made sure to be vapour-tight on the side of the higher vapour pressure. It is important to carefully select the appropriate products. So far, aluminium adhesive tapes were often used which tended to become brittle after some time (according to [2]).

Permanent action of load factors like temperature, moisture, mechanical load, radiation or chemical substances can induce aging effects in the envelope film and/or in the area of the welded and heat-sealed seams. These aging effects, which can cause failure of the panels, must be prevented. Vacuum insulation panels should be large in size, because heat conduction at the edges is clearly greater than in the centre. The air gaps between the panels should be kept as small as possible. These negative effects can be reduced by placing the panels in two layers. Structural fasteners at façade systems and webs made of conventional insulation materials or wood will produce clearly stronger thermal bridges as in conventionally insulated building components - the thermal bridge effect may be 5 to 10 times higher.

As ten years of experience in applying vacuum insulation panels have taught, particular care should be exercised when laying panels in the floor area. The following proven procedures are recommended: clean the substrate, lay a protective mat, lay the insulation panels, then lay another protective mat. It is considered to be an advantage if the upper protective mat consists of a conventional insulation panel. The joints were covered and the vacuum insulation panels are accessible.

Applications in the area of the building envelope

Due to their small thickness and their susceptibility to damage, the use of vacuum insulation panels in construction is associated with both benefits and disadvantages. [101]

Advantages:

- Clearly less thermal conductivity (factor 5 to 10) compared with conventional insulation materials
- Lean panels allow to gain space
- New options for retrofitting existing buildings
- New design options for new constructions and for renovating existing buildings

Disadvantages:

- Great susceptibility to damage during transport and installation
- Cannot be cut on the site
- Precise determination of the surface area required (dimensional tolerances of +/- 3 mm have to taken into account)
- Heterogeneous surfaces require small panels deviating from the standard panel forms
- High costs

As vacuum insulation panels presently are still very expensive, they will probably replace conventional insulation materials only in such places where the thickness of the insulation layer is limited (for structural or other reasons).

The following examples can be listed here:

- Floor of the ground floor level (when renovating existing buildings, for low construction heights)
- Terrace floors above heated habitable spaces
- Façades with a narrow building line near the (front) plot boundary
- Dormers
- Interior insulation
- Roller blind casing
- Window reveal

In many cases, the application of vacuum insulation can solve thermal problems that could have been solved hardly or not at all using conventional insulation materials. Vacuum insulation can be used for the following building envelope components:

- Floors and basement ceilings
- External façade
- Flat roofs
- Façade
- Terraces
- Lightweight structures

Vacuum insulation panels are also suited for prefabricated building components. In this case, the danger of damaging the panels is reduced since the building component is manufactured in the factory and not on site. Vacuum insulation panels are being used in various prefabricated building components:

- Timber panel elements
- Precast concrete elements
- Brick structures
- External doors
- Window parapets

Built examples

Renovation of a community centre using vacuum insulation

The community centre in Ulm-Böfingen (Germany) was modernized in the scope of the research programme “Energy optimised building“ (ENOB), funded by the German Federal Ministry for Economy and Technology (BMWi). The aim was to reduce the total primary energy consumption by at least 50 %. The community centre encompasses a community hall, a kindergarten and a rectory. The concept design was prepared by scientists of the Fraunhofer Institute for Building Physics who also accompanied the execution of the construction work and carried out validation measurements. A detailed description of the project is given in the final report [102].

Among a variety of renovation measures, retrofitting measures included the thermal insulation of the kindergarten floor and of the external rectory walls using vacuum insulation panels. On completion of the renovation measures, a two-year monitoring phase of the occupied buildings followed.

A: Kindergarten floor insulation with vacuum insulation panels

Design and execution

The kindergarten class rooms are located on the ground floor. The building has no basement. Figure 3.5-10 shows the ground floor plan. Prior to retrofitting, the floor construction consisted of:

- 66 mm cement screed
- 30 mm insulation
- 160 mm reinforced concrete

The U-value was equal to 0.96 W/(m²K). As the height of the floor construction could not be increased due to the height of the doors, it

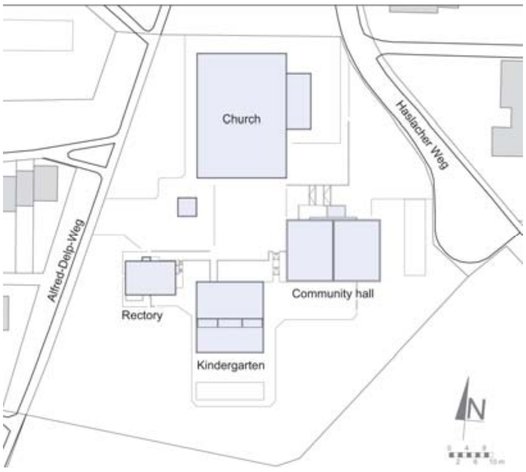


Figure 3.5-9
Site plan of the various buildings belonging to the community centre "Zum Guten Hirten“ at Ulm-Böfingen

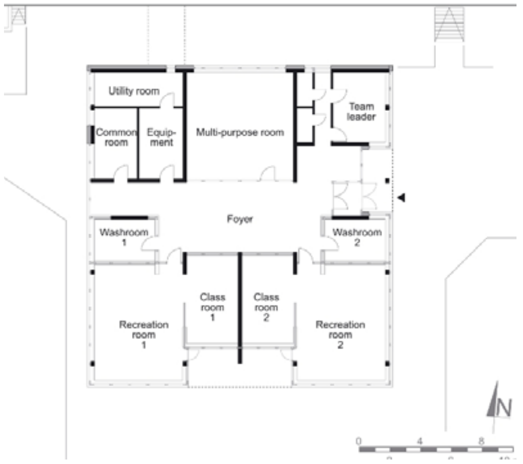


Figure 3.5-10
Floor plan of the kindergarten basement

was decided to use vacuum panels as floor insulation.

Figure 3.5-11 represents the floor construction. After applying the new moisture barrier onto the existing reinforced concrete floor slab an even bed of perlite was added to level the uneven structure of the floor surface. Subsequently, a 20 mm polyurethane insulating layer was added upon which the 20 mm vacuum insulation panels were laid.

The panels were produced and laid out according to a laying plan prepared by the manufacturer, based on a regular panel size of 1.20 m x 1.00 m. The smallest panels were sized 0.30 m x 0.25 m. Figure 3.5-12 shows the process of laying the vacuum insulation panels.

The panels were covered with a 10 mm layer of impact sound insulation. The base for the flooring is made of two bonded particle boards with a total thickness of 26 mm. If the floor could be covered with just one single vacuum insulation panel, the floor U-value would be equal to 0.18 W/m²K. Since it is inevitable that joints will be formed when the panels are laid, these joints have to be considered in the U-value calculations. Therefore joints of different widths were included in the calculations. The thermal bridge loss coefficients resulting for joints of various widths are compiled in Table 3.5-2.

Assuming a 4 mm gap between the panels, a mean U-value of 0.21 W/m²K will result. In Table 3.5-3 the layers of the floor construction and the related thermal conductivities are listed.

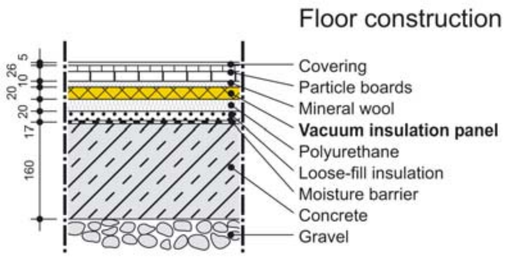


Figure 3.5-11
Kindergarten floor constructio

Figure 3.5-12
Laying vacuum insulation panels in the kindergarten

Table 3.5-2
Thermal bridge loss coefficients for various joint widths between two vacuum insulation panels (thickness: 20 mm) laid on the kindergarten floor

Joint width between two panels [mm]	Thermal bridge loss coefficient [W/mK]
2	0.0044
4	0.0061
6	0.075

Measurement results

To check the functionality of the vacuum insulation panels during use, temperature sensors were placed at several points when the panels were laid. The various types of these measuring points are presented in Figure 3.5-14. Measuring point I comprise 4 surface temperature sensors, which are placed

Table 3.5-3
Floor construction in the kindergarten, indicating the thermal conductivity of the individual layers. U-values are given for an ideal vacuum insulation panel (without joints) and for the real case (with joints).

Construction	Layer thickness [m]	Thermal conductivity [W/mK]	U-Value [W/m²K]	
			without joints	with joints
Flooring	0.005	0.171	0.18	0.21
Particle boards	0.026	0.170		
Mineral wool insulation	0.010	0.040		
Vacuum insulation panel	0.020	0.005		
PUR insulation	0.020	0.035		
Levelling loose-fill insulation	0.017	0.060		
Reinforced concrete	0.160	2.100		

below and above the polyurethane panel (laid under the vacuum insulation panel) and above and below the mineral wool panel (laid above the vacuum insulation panel).

Measuring point II comprises two surface temperature sensors: one placed below and one placed above the vacuum insulation panel; measuring points III and IV consist of just one temperature sensor (the former is placed beneath the vacuum insulation panel, the latter above). By analysis of the resultant surface temperatures in conjunction with the given indoor air temperature it is possible to clearly determine the condition of the panel: only an evacuated panel is fully functional. The thermal conductivity of a defective panel is about ten times that of an intact VIP.

The measurement positions are presented in Figure 3.5-14. In the multi-purpose room, for instance, there are 5 measurement positions (A through E): one position each of measuring point types I and III plus 3 type-IV positions. The temperature profile in the multi-purpose room at positions AI, BIII and CIV is represented in Figure 3.5-15. The values were recorded from January 23 to 27, 2007. Evidently, there is a massive difference between the temperatures measured above and below the vacuum insulation panel, which is due to the good insulation efficiency of the panel. This temperature jump is clearly higher than in the impact sound insulation, which is situated above the panel. Checks done by computer simulations proved the vacuum insulation panel to be fully functional. Measurement positions BIV (beneath the insulation panel) and CIII (above the insulation panel) feature the same temperatures as the sensors at measurement position A in the respective layer.

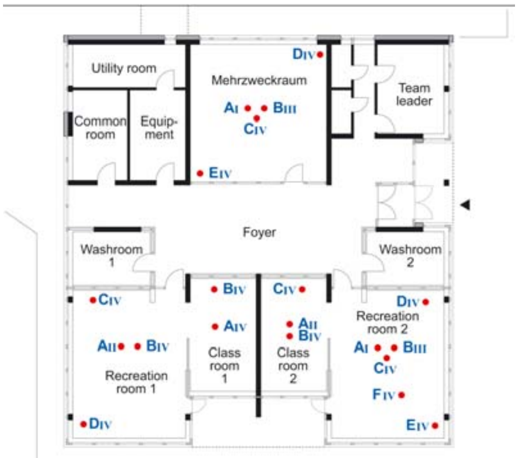


Figure 3.5-13
Representation of the kindergarten floor plan, indicating the measurement positions chosen for monitoring VIP long-term stability

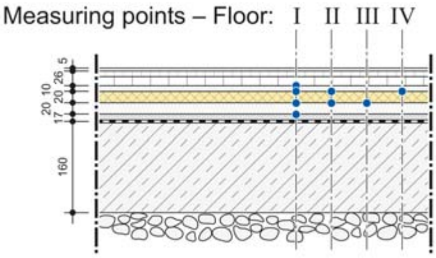


Figure 3.5-14
The kindergarten floor construction and the arrangement of the 4 measuring point types I, II, III and IV. Type I includes 4 sensors, type II 2 sensors; types III and IV have one temperature sensor each.

Examining the indoor air temperature, there is an evident temperature drop in the time when the kindergarten is not occupied.

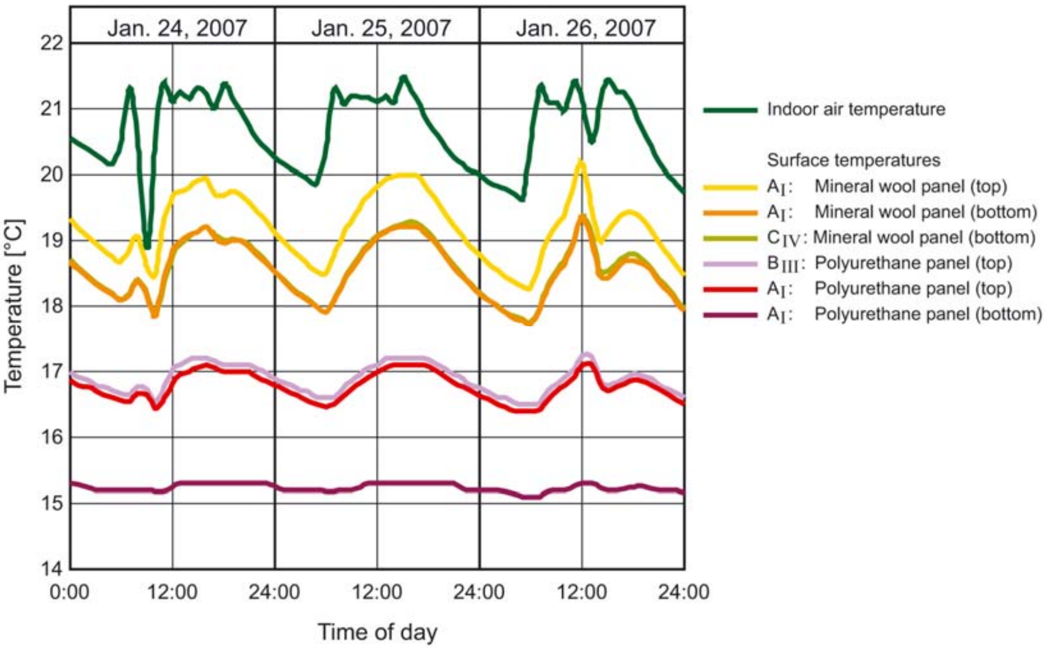


Figure 3.5-15
Representation of the surface temperatures measured at positions AI, BIII and CIV from January 23 through 27, 2007. There is a great temperature difference between the surface tem¬peratures measured below and above the vacuum insulation panel. The surface tempera¬tures at measurement positions AI, BIII and CIV are in good agreement at the lower and upper surface of the vacuum panel.

B: External wall insulation using vacuum insulation panels

Design and execution

The rectory of the community centre complex was built in 1966 as a reinforced concrete construction. The external walls had 60 mm core insulation. Renovation measures were governed by the architectural objective of avoiding any unnecessary changes in the building's appearance. Figure 3.5-16 shows the floor plan.

Prior to retrofitting, the wall construction consisted of

- 15 mm interior plaster
- 140 mm reinforced concrete
- 60 mm core insulation
- 70 mm concrete

The U-value was equal to 0.55 W/m²K. The renovation was intended to clearly reduce the U-value without increasing the wall thickness. On account of this requirement the builder decided to use vacuum insulation. The exterior concrete shell including the 60 mm core insulation was removed. As the exterior layer did not have a load-bearing function, it could be removed. Yet the process of dismantling turned out to be quite time-consuming since the outer shell was connected to the inner load-bearing concrete wall by several steel anchors. After removing the polystyrene layer the wall surface was found to be very uneven; a levelling render (mean layer thickness: 30 mm) had to be applied before mounting the insulation panels. It was planned to construct the new, VIP-insulated façade as a curtain wall. The thickness of the vacuum insulation panels was to be 30 mm. 12 mm fibre-cement boards with a width of 1.20 m were to be used as façade lining. The wall construction is represented in Figure 3.5-18.

The first concept presented by the façade builder, proposing to use the aluminium sub-structure ATK 601, resulted in a U-value of 0.35 W/m²K. The project team considered this value as much too high: assuming a 30 mm vacuum insulation panel without joints and without façade anchoring, a U-value of 0.15 W/m²K would result for this construction. This fact caused a revision of planning, eventually choosing the Gaubatz-Thermostar system, which consists of stainless steel brackets (thickness 3 mm) for fixing the vertical aluminium rails. These rails allow a greater distance in placing the fastening points compared to the ATK 601 system. The

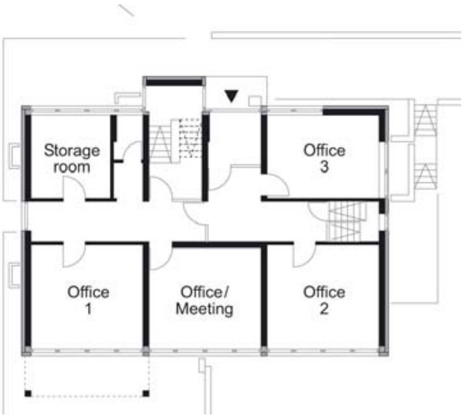


Figure 3.5-16
Floor plan of the rectory ground floor

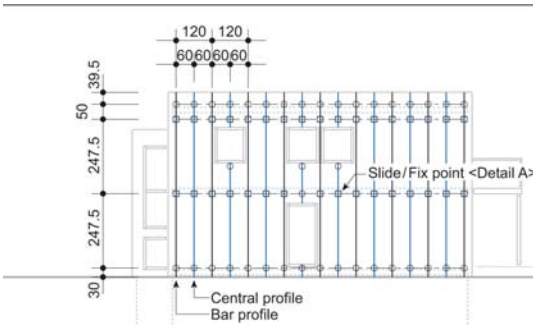


Figure 3.5-17
Representation of the vertical fastening pro¬files for the fibre cement boards of the curtain wall.

The profiles are fixed to the load-bearing wall by four brackets each.

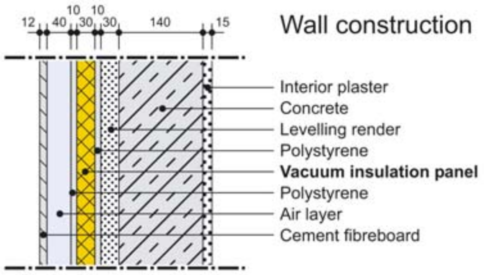


Figure 3.5-18
The rectory wall construction

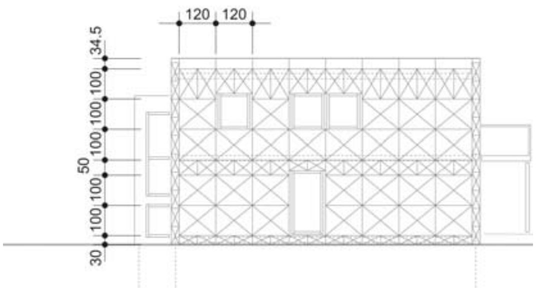


Figure 3.5-19
Representation of the laying pattern for the vacuum insulation panels

Table 3.5-4
Compiled thermal bridge loss coefficients for joints of different widths between two vacuum insulation panels applied to the rectory wall (thickness: 30 mm)

Thermal bridge	Value
Vertical joint, width 10 mm	0.0090 W/(mK)
Vertical joint, width 20 mm	0.0148 W/(mK)
Horizontal joint, width 0.2 mm	0.0022 W/(mK)
Bracket with stainless steel screw and thermostop	0.0149 W/K
Bracket with stainless steel screw without thermostop	0.0164 W/K

Construction	Layer thickness [m]	Thermal conductivity [W/mK]	U-value [W/m²K]	
			without joints	with joints
Interior plaster	0.015	0.350	0.15	0.28
Reinforced concrete	0.40	2.100		
Levelling render	0.030	0.870		
Insulation	0.010	0.040		
Vacuum insulation panel	0.030	0.005		
Insulation	0.010	0.040		
Air layer	0.040	–		
Fibre cement board	0.012	–		

Table 3.5-5
Survey of the rectory wall construction, indicating the thermal conductivity of the in¬dividual layers. U-values are given for an ideal vacuum insulation panel without any joints or anchors and for the real case with joints and anchors.

brackets are attached to the wall by stainless steel screws. Below the brackets there is a 5 mm insulation layer with a thermal conductivity of 0.1 W/mK.

The west façade with its vertical aluminium rails and the fastening points is represented in Figure 3.5-17. The arrangement of the vacuum insulation panels at the wall is shown in Figure 3.5-19. The width of the vacuum insulation panels was chosen such that the leg of the bracket is placed exactly between two panels. This is illustrated by the representation of the floor plan and section b-b in Figure 3.5-20.

To protect the vacuum insulation panels from damage they were covered on both sides with 10 mm polystyrene panels. The bonding was done at the façade builder’s workshop as the manufacturer supplies only uncoated vacuum insulation panels. The narrow sides were not coated, as this would have been time-consuming and unfavourable with regard to the thermal properties. Leaving the narrow sides uncoated however reduced safety because the panels can easily be damaged, particularly at the edges.

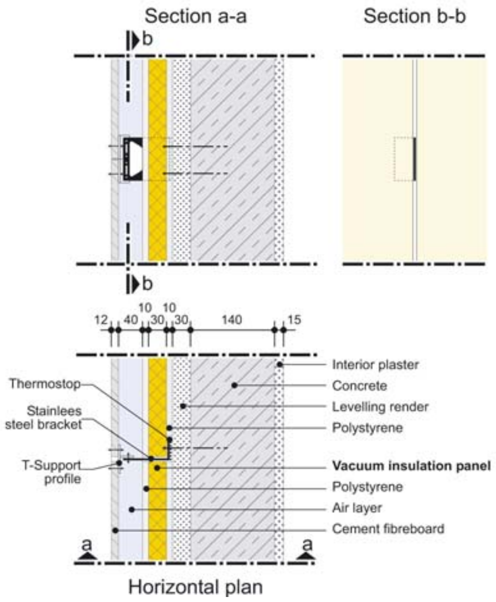


Figure 3.5-20
Representation of the fixing bracket (Detail A). The fibre cement boards are attached to the T-support profile. To reduce the thermal bridge effect, an insulating layer (‘Thermostop’) was placed underneath the bracket leg.

Figure 3.5-21 (left) illustrates the process of bonding protective polystyrene layers to a vacuum insulation panel. Mounting the coated panels is not really different from mounting customary polystyrene panels. First the adhesive was spread across the entire surface, then the panel was pressed against

Figure 3.5-21
Covering the vacuum insulation panels with polystyrene panels (left)

Mounting the polystyrene-covered vacuum insulation panels (right)

Figure 3.5-22
Representation of a fixing bracket. Between wall and bracket there is a 5 mm insulating layer termed 'Thermostop' (left).

Figure 18: View of the partially insulated west wall. Both sides of the vacuum insulation panels were coated with polystyrene panels (right).

the wall (see Figure 3.5-21, right). It was important, however, to make sure that the vertical leg of the fixing bracket was placed precisely at the panel joint. A small pocket had to be made in the polystyrene panel in the area where the bracket leg joins the wall. Figure 3.5-22 (left) shows a bracket with Thermostop below the bearing surface. When installing the panels it was found that exact measuring of the façade and the windows is decisive for the correct fit. If the panel sizes are not exactly fitted, there is no way to adapt the panels on site. Figure 3.5-22 (right) shows a view of the rectory's partially lined west façade.

By analogy with the kindergarten floor, the thermal bridge loss coefficient was once more determined for joints of different widths. The punctiform effect of the fixing bracket was also calculated. The results have been compiled in Table 3.5-5. The mean U-value of the façade construction given in Table 3.5-5 is equal to 0.28 W/m²a. Compared to a construction without any joints or anchors, the real U-value has almost doubled.

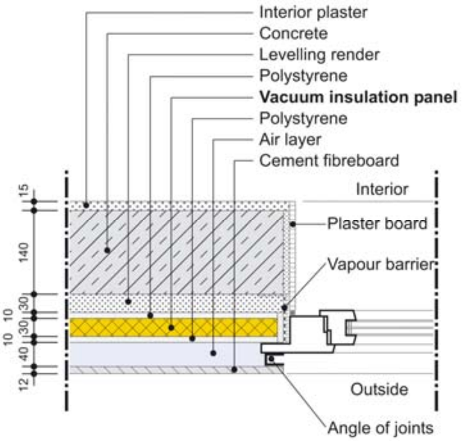


Figure 3.5-23
Plan of the window/ wall connection.

Figure 3.5-23 shows a horizontal section of the window connection. The window is placed exactly in the insulation level.

The connection of the façade insulation to the perimeter insulation is illustrated in Figure 3.5-24 (left). The fibre cement board is overlapping the junction joint. The attic was constructed in wood. External rigid foam

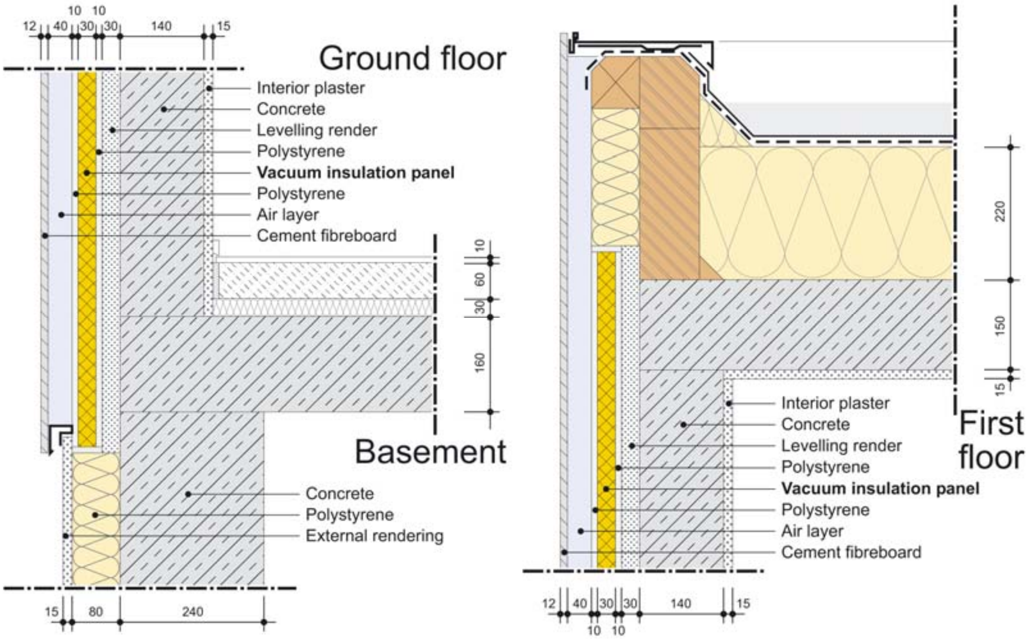


Figure 3.5-24
Representation of the wall cross-section in the basement/ ground floor area with connection to perimeter insulation (left)

Representation of the wall cross-section in the attic area (right) insulation was subsequently applied to its upper area (see Figure 3.5-24, right). This joint junction is also completely covered by the fibre cement board.

Measurement results

By analogy with the floor-slab measurements, temperature sensors were installed to check the functionality of the vacuum insulation panels in the wall area. Figure 3.5-25 shows the wall cross-section and the 4 different types of measuring points.

Measuring point I comprises 4 surface temperature sensors, namely: inside and outside of the internal polystyrene sheet, and inside and outside of the external polystyrene sheet. Measuring point II includes one temperature sensor inside and another one outside the vacuum insulation panel. At measuring point III one sensor was installed inside the VIP, while at measuring point IV one sensor was placed outside the vacuum insulation panel. In total, 22 measuring points were installed at the east, west, and north façades. Figure 3.5-26 shows the surface temperature profile at measurement position AI on the east façade. The temperature difference between the inside and outside VIP measuring points is almost 20 K. The three temperature peaks on the outside polystyrene panel and the VIP are due to solar radiation.

On the basis of the temperature difference between the interior and the exterior VIP surfaces, the considered vacuum insulation panel can be calculated to be fully functional.

Assessment of long-term behaviour

The essential lessons learned may be summarized as follows: The use of vacuum insulation panels was planned such as to achieve a reduction of the thermal transmittance. The installation of the insulation panels caused no problems. Long-term stability monitoring did not reveal any damages of the vacuum insulation panels up to the end of the observation period. Within the framework of the project it could thus be demonstrated that the U-value may be substantially reduced (at least by factor 2) by using vacuum insulation panels. In parallel, however, an increased planning effort is required to fully use the given potential of vacuum insulation panels - particularly with regard to preventing thermal bridges. In the scope of the project it could be shown that there was no aeration of the vacuum insulation panels during the two-year monitoring programme. To obtain data for a time period spanning several years, data collection should yet be continued for an appropriate term. In general, it could be demonstrated that - appropriate planning provided - applications of vacuum insulation

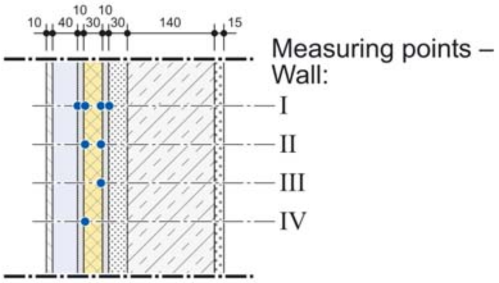


Figure 3.5-25
Representation of the rectory wall construction with arrangement of the 4 types of measuring points (I, II, III and IV). Type I comprises 4 sensors, type II consists of 2 sensors, types III and IV include just one temperature sensor each..

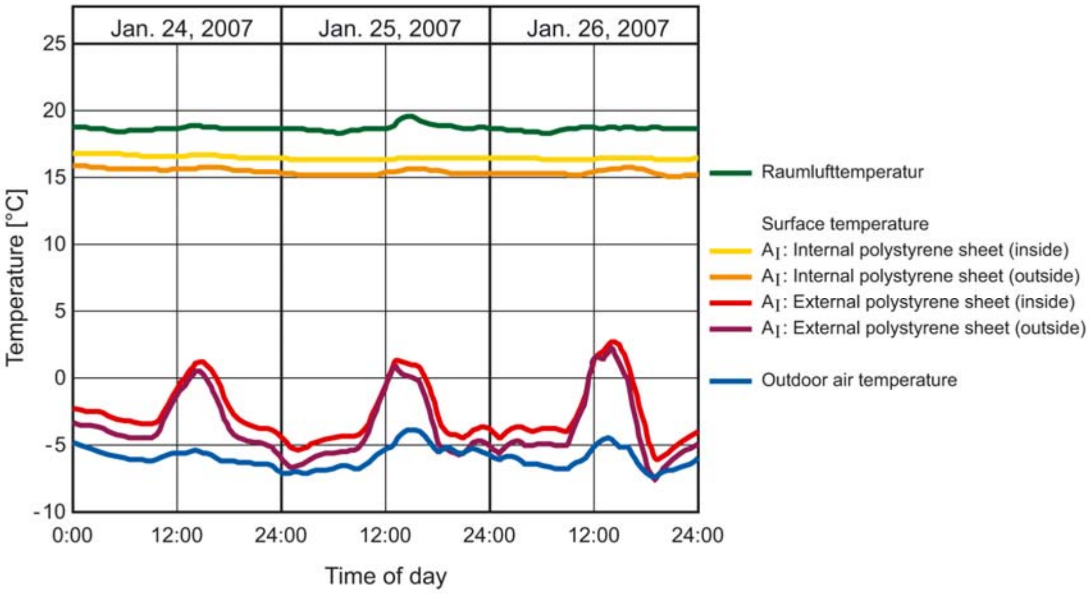


Figure 3.5-26
Representation of the surface temperatures measured at position AI on the east exterior wall from January 23 through 27, 2007. There is a great temperature difference between the surface temperatures measured inside and outside of the vacuum insulation panel. The re¬spect¬ive temperature differences resultant on the inner and outer surface of the polystyrene panels is comparatively low.

panels in building construction are practically possible and feasible for established architects and building contractors.

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3.5.3 Silica Aerogel Granulate

Johann Reiss

Aerogels are solid materials characterized by extremely high pore content (about 97%) and low solids content (about 3 %). The pore diameter is equal to 20 nm, approximately. At present, aerogel is the solid material with the least weight and the lowest thermal conductivity – which is why it is often termed 'frozen smoke'. Aerogels are used in various products, the manufacturers of which are mainly supplied with materials by Aspen Aerogels or Cabot Corporation. Other producers include Airglass, NanoPore, Taasi or Marketech International. Nanogel® Aerogel is the brand name Cabot Corporation use for their silica-aerogel products. Due to its very low thermal conductivity and its translucent nature, aerogel is used for filling narrow air layers in double-wall masonry constructions and for applications in daylight systems.

Production, properties, and applications

Aerogels are ultra-lightweight, high-porosity materials the largest part of which consists of air. Regarding the production process, two steps can be distinguished, namely the production of a gel interspersed with a solvent and the removal of the solvent by means of a specific drying process (supercritical drying). The material is produced [103] in a sol-gel process, which yields a colloidal mass reminding of a three-dimensional strainer. This mass is interspersed with a solvent and consists of fragile dendrites. For this purpose, aloxides (like tetraethyl orthosilicate, TEOS), alcohol and water are mixed with an appropriate catalyst (nitric acid, hydrochloric acid), by which a polycondensation process of the silanes is initiated, resulting in SiO2-networks and particles [104]. The solvent is then removed by an appropriate drying method, while the fragile, cross-linked open-cell aerogel structure remains.

Though drying under normal conditions does yield an aerogel, a shrinking process will be induced as the solvent volatilizes from the structural substance. This shrinking process is caused by the surface tension at the phase boundary of the solvent volatilizing from the aerogel structure. The surface tension at the phase boundary of the solvent escaping from the aerogel structure is sufficient to destroy the delicate aerogel structure. The end product is a porous structure with a pore content of about 50 %. The undesired process of shrinking can be prevented by supercritical drying. At sufficiently high temperatures and pressures, the critical threshold of a fluid will be crossed. At this point, the liquid-vapour phase boundary will vanish, and so will surface tension. This method allows to produce silica aerogels with densities of down to 20 kg/m³, which corresponds to a pore content of 99 % (for comparison: an ordinary drying process will yield an aerogel having about half the thickness of customary glass, i.e. approximately 1,000 kg/m³). In the 1930s, Kistler was the first researcher who managed to produce silica aerogels with a density of only 20 kg/m³, corresponding to a material porosity of 99 %. It was his merit to have found a method for drying gels containing liquids without shrinkage, i.e. saving the initial gel structure. This method employed supercritical drying [105].

Aerogels can be produced from a variety of substances. Most widely studied were fused silica and waterglass aerogels [106], [107].

The pore diameter of aerogel is smaller than the mean free path of an air molecule. Due to this property, heat conduction in the gas phase is strongly reduced. Block-type aerogel, as shown in Figure 3.5-27, is extremely lightweight and very prone to breaking under non-uniform pressure.

Figure 3.5-27
Block-type aerogel

Source: ASPEN AEROGELS, INC, www.aerogel.com

Figure 3.5-28
Piles of Nanogel® Aerogel

Source: Cabot Corporation, www.cabot-corp.com

The method developed by Kistler was very time-consuming. Cabot Corporation has now developed a manufacturing method to produce aerogels for building applications at a more reasonable price. For better processing, the material marketed as Nanogel® Aerogel is produced in granular form; Figure 3.5-28 shows the material when piled up. Regarding building applications, Nanogel Aerogel includes the following performance benefits:

- Low thermal conductivity
- Light transmittance
- Light fastness
- Long service life
- Temperature stability
- Weather resistance
- Corrosion resistance
- Low net weight
- Sound absorption
- UV stability

Due to these properties, the material is suited both for applications in opaque wall areas (as loose fill or 'blown in' insulation in double-wall masonry) and in the area of transparent envelope components (to use daylight). The material properties are compiled in Table 3.5-6.

External walls are often constructed as cavity walls, consisting of an inner, load bearing wall and faced brickwork. Between these walls there is an air layer; air supply and extract openings provide a connection to the outside air. This air gap is only a few centimetres wide. Nanogel Aerogel is ideally suited for backfilling this gap: due to the material's low thermal conductivity, the application of just a thin insulating layer will significantly improve the wall's U-value. The German Institute for Building Technology (DIBt) has issued a general technical building approval for the use of Nanogel Aerogel in loose-fill cavity-wall retrofitting applications. The document specifies the design value of the thermal conductivity to be 0.21 W/mK.

To fill in the insulating material, holes are drilled into the building façade, through which the granular material will be introduced (see Figure 3.5-29). In this process the insulating material is compacted in such a way that the cavity will be filled completely, without leaving gaps.

Due to the small grain size, it is sufficient to make small holes in the joints of the facing masonry (see Figure 3.5-30) to introduce the granulated material.

Due to their high degree of translucence, aerogels are also suited for the production of translucent envelope surfaces. The translucent components are manufactured by filling in the

Table 3.5-6
Survey of material properties

Designation	Parameter
Particle size	0.5 – 4.0 mm
Pore diameter	approx. 20 nm
Porosity	>90 %
Bulk density	90 100 kg
Thermal conductivity	0.018 W/mK
Vapour diffusion resistance	2 – 3
Surface chemistry	fully hydrophobic
Fire resistance class	B1
Sound velocity	100 m/s
Price	approx. 1200 €/m³

Table 3.5-7
Physical properties of aerogel layers of varied thickness
[www.cabot-corp.com]

Thickness	Light transmissin	g-value	U-value
mm	%	%	W/m²K
13	73	73	1,40
25	53	52	0,70
31	45	43	0,57
38	39	39	0,47
50	28	26	0,35
64	1	21	0,28

Figure 3.5-29
Backfilling the wall cavity through a hole in the outer shell of the masonry.
Source: InnoDämm GmbH, www.innodaemm.de

Figure 3.5-30
Opening to introduce the blow-in insulation in the joint area of the facing brickwork.
Source: InnoDämm GmbH, www.innodaemm.de

aerogel granules into the space between glass panes or into the voids of skinned plastic sheets. If radiation is incident on such a component, the light will be diffused and transmitted into the room without causing glare effects. Granular aerogel is UV-resistant, water-repellent, and has a low thermal conductivity. The translucent components are particularly suited for applications in

- Museums
- Sports facilities
- Administrative buildings
- Production halls.

Areas of application include:

- Façades
- Roof lights
- Roofs of halls and glass-roofed wells.

Compared to triple glazing, these components have the advantage of less weight. Particularly in renovation projects, structural considerations often require to control the weight of components (glazed roofs, for instance). Table 3.5-7 gives a survey of some physical properties of aerogel layers of different thicknesses. Figure 3.5-32 shows an insulating glass panel made by Okalux [108]. It provides high-performance thermal insulation and ensures uniform, glare free scattering of incident daylight in the room. It is suited for all applications that require diffused daylight (like museums, sports facilities, and production plants).

Apart from the insulating glass panels, also aerogel- filled Plexiglas multi-skin sheets (see Figure 3.5-31) are available. Compared to insulating glass panels, these Plexiglas multi-skin sheets have significantly less weight.

Another manufacturer, Scobalit, offers double-walled, Nanogel-filled composite panels made of glass-fibre reinforced polyester resins [110]. These panels have a maximum length of 8.0 m and a maximum width of 2.40 m. The properties of these panels are compiled in Table 3.5-8.

The Nanogel-filled glazing products and multi-skin sheets have an advantage over 'glass only' products: the U-value does not depend on the inclination of the installation. It will be the same for horizontal positions of installation and for vertical orientations. In the case of such 'glass only' products, the resultant U-value of the inclined installation orientation will be higher than for the vertical position.

Table 3.5-8
Properties of Scobatherm-Nanogel components [110]

Properties	
Thermal conductivity	0.0219 W/mK
U-value	0.41 W/m²K (thickness of component: 50 mm)
g-value	about 25 %, depending on thickness of component
UV light transmission	very strong absorption
Infrared light transmission	clearly reduced
Sound absorption	about 27 to 30 dB
Temperature resistance	-40 °C to +120 °C
Fire resistance	B1

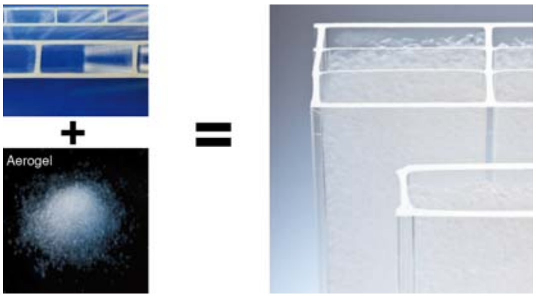

Figure 3.5-31
Opening to introduce the blow-in insulation in the joint area of the facing brickwork.
Source: InnoDämm GmbH, www.innodaemm.de

Figure 3.5-32
Insulating glass panel [108]
Source: OKALUX GmbH, www.okalux.de

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3.5.4 Aerogel insulation blankets

Johann Reiss

On behalf of NASA's Kennedy Space Center, Aspen Systems Inc. has developed a wide range of products designed for diverse aerogel applications [111].

One of these applications is the production of fibre-reinforced composites based on aerogel-impregnated insulating fleece material, so-called aerogel blanket insulation. Initially, these aerogel blankets were primarily used to insulate oil pipelines, as the use of thinner insulating layers reduced the costs for laying pipelines [112]. Recently, building applications of aerogel insulation blankets have become much more popular. Depending on the respective manufacturer and the intended use, these products are termed Spaceloft, Cryogel, Pyrogel, Spacetherm, or Nanogel Aerogel Thermal Wrap.

Production, properties and applications

The production of these blanket insulation materials starts with preparing a liquid mixture of aloxide, alcohol, water, and a catalyst to obtain a sol as a preliminary stage in the aerogel production process, which is then applied to a fibre tissue [112].

This fabric is an insulating felt made of polyester glass fibres, to which silicon dioxides are applied [115]. For blankets that have to meet stricter requirements (like Cryogel, Pyrogel for industrial applications), silica [115] or carbon fibres are added as carrier material, plus additives like titanium dioxide or aluminium hydroxide [113].

Under influence of heat, the components will react and turn into an amorphous, solid network structure (gel). In the course of a subsequent chemical treatment, the gel will solidify completely and the material receives its hydrophobic properties. Under high pressure and high temperature the liquid is removed from the mixture, resulting in aerogel-impregnated fibre blankets [112].

After drying, the fibre composite combines the positive insulating properties of aerogels and the wide application potential of insulating felts. The new insulating material is flexible, robust and easy to process. There are various aerogel blanket insulation products suitable for different areas of application, termed Spaceloft, Cryogel, and Pyrogel. A schematic of the manufacturing process is shown in Figure 3.5-33.

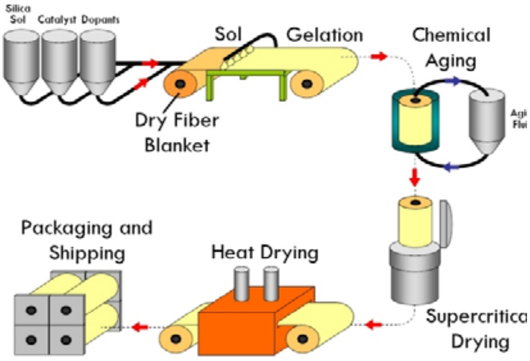

Figure 3.5-33
Manufacturing aerogel insulation blankets [112]

Source: www.aerogel.org/

Spaceloft®

Spaceloft® is a versatile, nanoporous aerogel blanket (see Figure 3.5-34). It consists of an insulating felt made of polyester glass fibre, to which silicon dioxides are applied. The additive is magnesium hydroxide. This blanket-type insulation is used for insulating interior and exterior walls, rear-ventilated façades, flat roof constructions, terraces, floors, and base slabs. Further, it is suitable for applications at window sills, window reveals and window lintels as well as in roller blind boxes and radiator niches [114].

Figure 3.5-34
Spaceloft blanket [115]

Source: Stadur-Sued Daemmstoff-Produktions GmbH. www.stadur-sued.de/produkte/aerogels/spaceloft/

Table 3.5-9 gives a survey of the key physical properties for building applications.

Further properties relevant to applications in the building sector include:

- Easy-to-use, excellent working properties (bending, cutting, punching etc.)
- Lightweight, flexible, space saving, and non-toxic
- Can easily be used with / attached and/or bonded to other materials
- Does not absorb moisture

The fleece-type material comes in large rolls of about 1.40 m width like a made-to-measure wall-to-wall carpet, wrapped in a plastic film or laminated to building facing boards (also multi-layered)

- Ageing: Constant properties and values independent of time, temperature, or moisture
- Environment: the production of Aspen Aerogel products requires low energy input, namely 71.6 MJ/m^2. The share of CO_2 is equal to 5.74 Kg/m^2.
- Sound insulation: Apart from offering efficient heat/cold insulation, this product is also distinguished by good sound-proofing properties.

More detailed product information available at (ww.aerogel.com)]

Application for general technical building approval has been filed [115].

Cryogel® Z

This product is flexible aerogel blanket insulation (see Figure 3.5-36) with an integral vapour barrier for sub-ambient and cryogenic applications [114]. It is particularly suited for low-temperature applications like insulating refrigerating lines and plants, liquid gas lines and plants, cooling plants or ventilation systems. Cryogel blanket insulation is manufactured in thicknesses of 5 mm and 10 mm. Thermal conductivity is temperature dependent, as shown in Table 3.5-9.

The material is distinguished by its extremely low thermal conductivity, low weight, high vapour diffusion resistance and ease of use.

Figure 3.5-35
Pyrogel blanket [115] [37]

Source: Stadur-Sued Daemmstoff-Produktions GmbH. www.stadur-sued.de/produkte/aerogels/spaceloft/

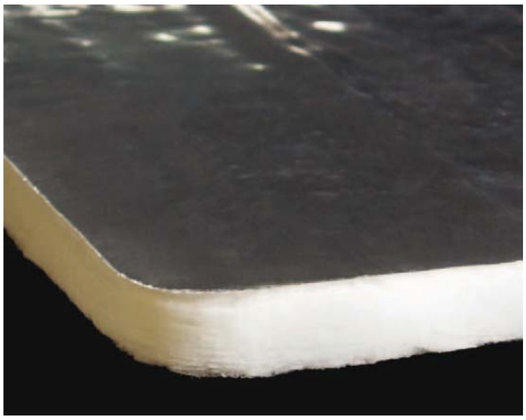

Figure 3.5-36
Cryogel blanket insulation [37]

Source: Stadur-Sued Daemmstoff-Produktions GmbH. www.stadur-sued.de/produkte/aerogels/spaceloft

Pyrogel®

The Pyrogel blanket (see Figure 3.5-35) consists of silica and carbon fibres [115] including the additives titanium dioxide, aluminium hydroxide, and magnesium hydroxide [114].

Designation	Pyrogel	Spaceloft
Thickness	5 mm and 10 mm	5 and 10 mm
Thermal conductivity acc. to EN 12667 at 100°C	0.023 W/(mK)	0.131 W/(mK)
Temperature resistance	-40 °C through +650 °C	-200 °C through +200 °C
Mass per unit value	180 kg/m³	150 kg/m³
Compressive strength at 10% deformation	102 kpa	70 Kpa
Compressive strength at 25% deformation	183 kpa	210 Kpa
Diffusion resistance	-	11
Equivalent thickness of air layer sd	-	0.11 m
Hydrophobicity	yes	0.83 mWs
Fire resistance	Euroclass A2 acc. to EN 13501-1	Euroclass C acc. to EN 13501-1

Table 3.5-9
Material properties of Spaceloft and Pyrogel blanket insulation [114]

Average temperature [°C]	-200	-150	-100	-50	0	50	100
Thermal conductivity [mW/(mK)	9.8	11.4	12.3	12.9	13.8	15.5	18.6

Table 3.5-10
Thermal conductivity

As the blanket is suited for high temperature applications, its preferred use is in areas where strict fire safety requirements apply: exemplary applications include insulation of pipelines, tanks, domestic appliances, uses in transportation and in the aerospace industry [114].

Table 3.5-9 gives a survey of the key physical properties for building applications [114].

Applications and advanced products

Likewise, combinations with other insulants and materials are possible [116].

There are several companies that provide aerogel blankets with various protective surface layers for better handling. For instance, Stadur-Sued GmbH [115] and Proctor Groups [116] have developed solutions, in which aerogel blankets are applied to particle board, plywood, gypsum fibre boards, aluminium panels or plasterboard sheets that can easily be attached to various substructures [117], (see Figure 3.5-39 to Figure 3.5-40).

The product Spaceloft Insul-Cap (which is represented in Figure 3.4-41) is a 10 mm strip of aerogel fabric that was provided with double-sided adhesive tape on either surface. This allows for the retrofit insulation of window and door frames.

Figure 3.5-38 shows the thermographic image of a façade. The upper floor was retrofitted with Spaceloft Insul-Cap, the lower floor was not. The difference is evident.

Depending on the framing material, the thermal resistance can be improved by up to 40 percent.

Exemplary applications

Besides industrial applications, aerogel blankets are used in the building sector primarily in renovation projects because retrofitting of existing buildings leaves only limited space for placing additional insulating material. Unlike rigid, preformed insulation components like pipe collars or panels, aerogel blankets can be applied to closely fit almost any kind of shape or configuration. Apart from using these blankets for external or internal insulation, typical areas of application include reveals, window sills, roller blind boxes, radiator niches, perimeter slab insulation, floors, piping, roof exit openings, or terraces [116].

At present, aerogel insulation blankets have not yet received general technical approval by

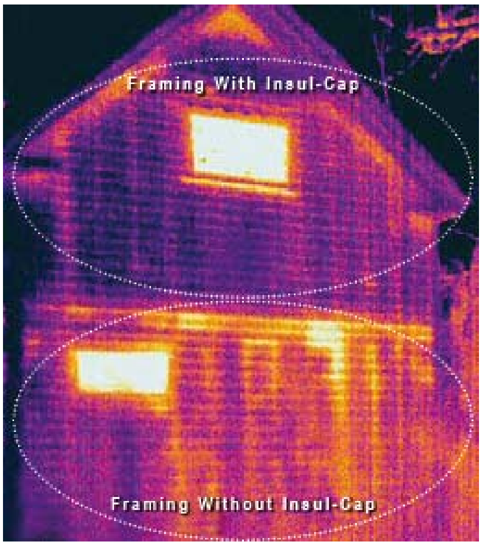

Figure 3.5-38
Thermographic image of a façade the upper floor of which was insulated with Spaceloft Insul-Cap (in contrast to the uninsulated lower floor) [118]
Source: Aspen Aerogels. www.aerogel.com

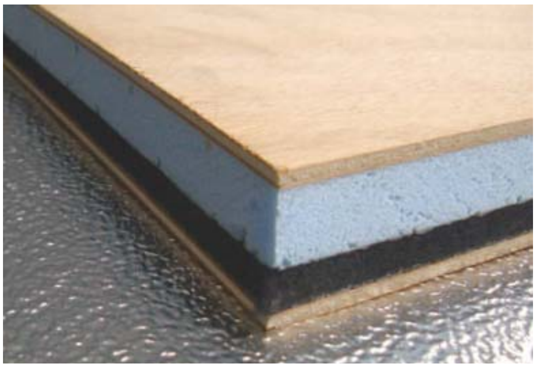

Figure 3.5-39
Composite panel with plywood, extruded polystyrene and aerogel fleece [115]

Source: Stadur-Sued Daemmstoff-Produktions GmbH. www.stadur-sued.de/produkte/aerogels/spaceloft/

Figure 3.5-40
Composite panel with aerogel fleece and aluminium panels on either side [115]

Source: Stadur-Sued Daemmstoff-Produktions GmbH. www.stadur-sued.de/produkte/aerogels/spaceloft/

Figure 3.5-41
Retrofitting framing insulation using Spaceloft Insul-Cap [118]
Source: Aspen Aerogels. www.aerogel.com

the supreme building authority in Germany, which is the reason why pilot projects are mainly found beyond German borders (in Switzerland, particularly) [114].

External insulation

Regarding external insulation, the first large building to be renovated was an old mill in Oberhallau in the Swiss canton of Schaffhausen (see Figure 3.5-42). Built around 1608, the mill was retrofitted in 2007 for conversion to fit its new use as a mill museum, including an integrated dwelling. The present owners required comprehensive and careful renovation to preserve the historical monument and to remove the visible effects of insufficient maintenance the building had suffered during the last 110 years [119]. As the old stone structure inside the building was to be uncovered and the wooden construction had to be protected from surface condensation, large-scale internal insulation was discarded [119].

Hence, an external construction was favoured, which however had to meet the requirement to preserve the historical appearance of the masonry work, ensuring installation of windows flush with the façade. Thus any conventional external insulation was excluded. Instead, two layers of aerogel blankets were applied (each one with a material thickness of 9 mm), secured by a metal net and then plastered. In this way, the former U-values of 1.0 W/m²K could be clearly reduced. [118]

The blankets were also used (as strips) in the internal space below the radiators and around the new wooden windows, which replaced the old ones almost without exception. Likewise, the roof construction was renewed, and aerogel blanket insulation was applied to the floor in the main building and along the foundation. Further, new building systems including a distribution network were installed. Since these retrofitting measures were implemented, the indoor environment remains comfortable even on cold days [119]. Figure 3.5-43 to Figure 3.5-46 show how the insulation was mounted.

Figure 3.5-45 shows the building after renovation.

Further areas of application

The use of aerogel blankets is also recommended for timber constructions where this material is highly appreciated, particularly due to its quality of being open to diffusion. Besides, the blankets are now used much more often for insulating terraces or flat roof constructions.


Figure 3.5-42
Existing building before renovation [114]
Source: Agitec. www.agitec.ch/


Figure 3.5-43
Mounting Spaceloft aerogel blankets [114]
Source: Agitec. www.agitec.ch/


Figure 3.5-44
New exterior wall insulation [114]
Source: Agitec. www.agitec.ch/

Moreover, this material is suited to eliminate punctiform thermal bridges. When retrofitting a Freiburg (Germany) tower building for passive standard, five layers of aerogel blankets were used in the area of the roller blind boxes (see Figure 3.5-47).

Figure 3.5-45
Fixing and coating of aerogel blankets [114]

Source: Agitec. www.agitec.ch/

Figure 3.5-46
View of the building after retrofitting [114]

Source: Agitec. www.agitec.ch

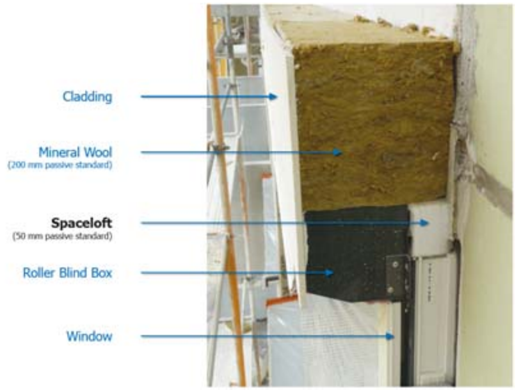

Figure 3.5-47
Insulation of roller blind boxes [118][40]

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3.5.5 Solar facade for building rehabilitation with minimal energy consumption

Giuseppe Fent, Architekt HTL

Eric Nelson, MSc, MArch

Introduction

To attain the lowest energy house standard, commonly, insulation in excess of 35cm (glass wool, mineral wool, or wood wool) is necessary. Such a super insulated wall system can become easily more than 60cm thick. Thick walls, however, can pose space problems or a variety of other problems, i.e., in detailing openings/transitions or by diminishing daylight from entering rooms.

The solar facade is a relatively new system that is gaining more and more attention. Due to its physical qualities it can produce great thermal transmittance values (U-values) with far less insulation. Although it does not completely replace conventional insulation, it can function with 50% less equally well. A solar facade works on a different basis than an ordinary cladding system by absorbing solar energy into its system, thus creating a thermal buffer around the building's outer wall surface. This greatly reduces the differential from the outside to the inside air temperature, hence reducing thermal transmission losses significantly. This concept of passive heating/cooling of the cladding system can reduce the overall wall thickness by 25-50%.

Solar facade - The Lucido® concept

Lucido® is a multi-component cladding system made up of a cast glass facing (4mm) with an air space (16mm) and a lamellae structured wood absorber (40mm) behind it. The front half of the absorber is made up of lamellae structures and the rear half is a solid core acting as the main thermal mass. The system has openings on the bottom and the top allowing the air to flow freely and moisture to escape, hence no mildew can form. The system can be mounted on any wall system, massive or light. All components are held together mechanically with aluminium brackets and rubber (EPDM) seals.

As most solar facades, Lucido® works like rechargeable batteries on a day-night cycle. The wood absorber acts as the battery that gets charged with solar energy during the day, drained during the night, and recharged all over again the next day. However, the thermal effects are different from the summer cycles to the winter cycles.

Figure 3.5-48
Façade with the Lucido system applied

Summer

During the summer, with the high standing sun, the lamellae structures act like a self-shading device preventing the solar rays from penetrating the absorber's wood core. It absorbs less energy thus lowering the facade's surface temperatures overall. The hot air in the channel rises and escapes through the openings on the top while drawing cooler air in from the bottom, further helping the system from not overheating.

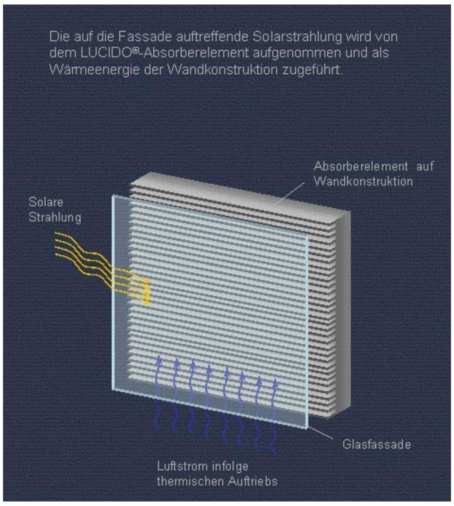

Figure 3.5-49
Construction of the Lucido concept

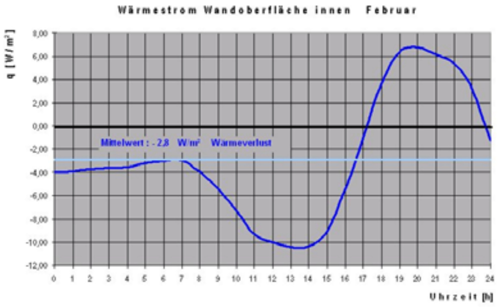

Figure 3.5-50
Heat flow in a wall during the course of the day

Winter

During the winter, on the other hand, the low angled solar radiation can penetrate into the lamellae structure being therefore, the wood core absorbs it more effectively. Due to a 3 to 1 surface ratio, compared to a regular flat facade, more energy can be absorbed. The thermally charged absorber then creates a buffer to the outside climate, greatly reducing the temperature differential to the inside, consequently also reducing the thermal transmission losses. The cooler, more stagnant air in the channel creates insulation, preventing the wood absorber from losing all its heat through convection to the outside air, which is typically the case with conventional cladding systems.

Figure: Heat flow across the interior wall surface – February: The average thermal transmission loss over a 24 hour cycle does not characterize the actual thermal behaviour, especially what happens after sunset. The recorded losses between 8.00h and 16.00h are typically compensated by the gains through the windows. Thus, proper tuning of the system can produce a positive energy balance over ¾ of the day.

Spring/Fall

The true strength of the Lucido® lies in the transitional seasons where high temperature amplitudes mark the daily cycle. Enough solar energy can be absorbed during the day to maintain comfortable temperatures during the night, so that heating is no longer necessary. With a solar facade system the heating period is shorter than with a conventional cladding system.

Winter thermal insulation

Significant reduction of heat loss through:

- Optimal use of solar radiation through Lucido:
  Solar radiation is absorbed by wood absorber
- Reduction of the heat transfer through the outer wall surface:
  Through a glass facing protecting the thermal buffer zone in the lamellae structure from wind
- Optimal use of the phase shift taking place in the Lucido® system:
  The heat flow entering during noon time is, depending on building type released to the interior spaces → ENERGY OPTIMIZATION

Summer thermal insulation

Prevention of summer overheating through:

- Optimal use of the phase shift taking place in the Lucido® system:
  The heat flow setting in at noon doesn't reach the interior wall surface until early morning hours the next day
- Optimal layout of the amplitude reduction of the Lucido® system:
  The surface temperature amplitude is diminished by the wood absorber
- The interior surface temperature is therefore reduced to a minimum

Performance and climate

Lucido® is a system that lives off solar radiation, hence the orientation to the sun, as well as the amount of solar radiation, is influential to the performance of the system. The south facing facade has the best performance, followed by the east and west facades. The north facing facade has the weakest performance to where the investment in a more expensive system becomes questionable. This also means that the system's performance cannot simply be expressed with a single U-value. The actual U-value "U_{eff}" (effective) is determined based on monthly radiation averages for each facade orientation for any geographic location. The Lucido® system has been optimized to suit the central European climate, meaning the angle of the lamellae, the size of the absorbers, as well as the air space, is finely adjusted to perform equally well during the summer and winter. As a drawback, the performance can be weakened through shading from surrounding topography, vegetation, or other buildings. The system can accept some shading, but not too much. Thus an open unobstructed location is beneficial for a solar facade system. Even in alpine regions Lucido® performs really well as long as the mountains do not obstruct the sun too much.

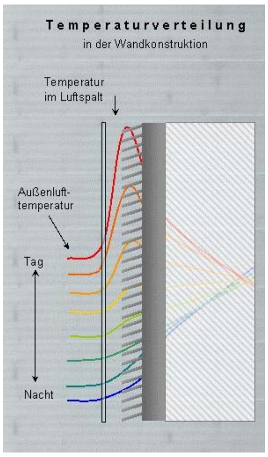

Figure 3.5-51
Temperature distribution in the Wall

The greater radiation with altitude compensates for the lower temperatures.

Investment and ecology

Since the system consists of multiple components it is rather laborious to install. On top of that the parts are somewhat pricy making the whole system cost intensive. Nevertheless, it is a system that has a long lasting life expectancy and can be applied in a wide range of rehabilitation projects and new construction. Lucido® is an elegant system that can be applied to any building type.

Advantages

- Excellent U_{eff}-values for the sun-facing sides, S, E, W with 40-50% less insulation
- Thinner walls
- Due to its slim wall structure, connection/transition details are simpler and cheaper
- Usable heat gain throughout the winter
- The absorber does not degrade like insulation does
- The wood is protected from weathering, hence it does not turn grey
- All materials are mounted with mechanical fasteners and are easily removable
- Removed components can easily be separated and recycled
- High grade materials with long life expectancy, low CO_2 footprint
- Low maintenance - glass panes can be replaced individually for repair or cleaning

The cost intensity is compensated with the effectiveness of the system, the high-grade materials' life expectancy, and recyclability of the component and the low maintenance.

Example of a single-family home rehab project in Lanterswil, TG, Switzerland

The original house was a bar building without any kind of insulation. The calculated U-value based on a wall section was at the time 1.5W/m²K. Beginning in 2005 the building was completely rehabilitated. The walls were insulated with 10cm of wood wool insulation and the Lucido® system. The roof received 32cm of insulation (Homatherm), hence including the attic into the thermal envelop. All the windows were replaced. A new air supply system and also a photovoltaic system were installed. A photovoltaic system of 20 m² with a power of 2.4 kWp was installed on the roof.

Figure 3.5-52
View of the demonstration building before renovation

Figure 3.5-53
View of the demonstration building after renovation

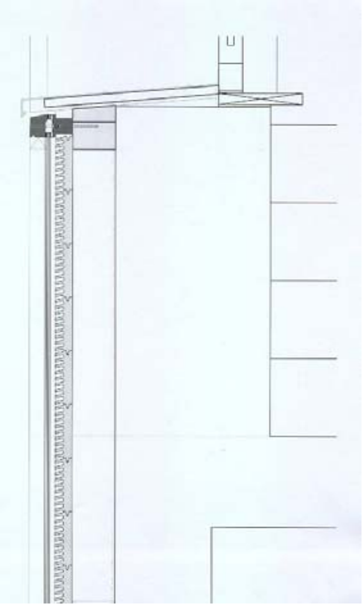

Figure 3.5-54
Cross Section of the Lucido wall

Before the rehabilitation the energy consumption for the house was 148kWh/m²a for 95m² living area. After all the rehabilitation measures the overall energy consumption level dropped 80% to 28kWh/m²a with added living area of 135m².

Following U_{eff}-values were calculated for the heating months October through April:

Ueff S:	-0.02 W/m2K
Ueff O:	0.08 W/m2K
Ueff W:	0.07 W/m2K

Ueff N: 0.15 W/m2K

The rehabilitation of this project increased the living space by 50% while at the same time reducing the energy consumption of the heat pump by 50%. This project shows how much a rehabilitation of a building can bring. Since many houses are not ready to be torn down for many more decades or even centuries, it is important to invest our efforts in reducing our energy consumption by rehabilitating one house at a time.

The solar facade poses an excellent alternative, and in some cases, it is clearly the preferred system over a conventional insulation system. As our experience increases and matures we find more and more qualities of the system. Some people like its versatility of the slimmer walls, others appreciate the low ecological impact of the material being used, and yet others simply like the modern look of a natural wood wall covered in glass. The physical qualities have been proven mathematically and empirically in the many projects that have been completed. Using the solar power in the building envelope is another development in the right direction of sustainable building practices in learning how to harness the endless power of the sun.

4 Ventilation

4.1 Ventilation in retrofit

Olivier Pol / Wolfgang Leitzinger

4.1.1 Introduction

Increasing the air tightness of building envelope is of the main conditions for obtaining high energy performance in the buildings being renovated, mainly because it allows for reducing the heat energy losses through infiltrations. This measure needs to be associated with the installation of a mechanical ventilation system mainly because:

- the fresh air supply which was guaranteed by uncontrolled infiltration rate before renovation works can not be ensured in that way anymore if air tightness of envelope is increased. This can lead to a bad air quality corresponding to a high CO2-concentration in internal air (>600ppm). More details on this issue are presented in the Subtask D booklet.

High air tightness corresponds also to a vapour barrier hindering humidity transfer through the building envelope. In winter, high relative air humidity rates can be observed in case of insufficient infiltration or natural ventilation rate. If thermal bridges have not been accurately handled during renovation works and the humid internal air gets in contact with the cold side of the building envelope, there is a risk of condensation which can lead to constructive damages if during rest of the year, the water condensed can not evaporate entirely.

The reasons mentioned here are sufficient to support the fact that mechanical ventilation systems are indispensable when dealing with advanced housing renovation: manual window opening usually don’t guarantee a sufficient air change rate as the frequency of window opening only depends on user behaviour. Natural ventilation concepts might be interesting low energy solutions, but in housing renovation projects the possibilities are more limited than in new buildings.

4.1.2 Normative Aspects

Before providing further recommendations on ventilation system design, it is necessary to summarise the contents of international and national standards available for ventilation systems in the housing sector. In particular it is important to know which type of requirements is provided in which standard.

The following European standards apply to ventilation systems in residential buildings.

4.1.3 Status of ventilation systems in standardization activities

The following standards apply to ventilation systems in residential buildings:

Austria:

ÖNORM H 6038 – controlled (balanced) mechanical supply and exhaust ventilation for dwellings including heat recovery. The H 6038 is not very restrictive. It defines the main components of a controlled ventilation system and minimum design requirements but it does not require the compliance of quality criteria.

Germany:

VDI 6022: hygienic requirements for ventilating and air-conditioning systems and air-handling units

European Standards:

EN 15665:2009 - Ventilation for buildings - Determining of performance criteria for thedesign of residential ventilation systems

CEN/TR 14788:2006 - Ventilation for buildings - Design and dimensioning of residential ventilation systems. Stand alone and hybrid systems (combination of mechanical and free ventilation) are handled in this technical guideline.

EN 13465:2004 - Ventilation for buildings - Calculation methods for the determination of air flow rates in dwellings. This standard provides a calculation method to determine the minimal fresh air supply rate for the different parts of a dwelling (sleeping rooms, kitchen, living room).

EN 13779:2007 - Ventilation for non-residential buildings - Performance requirements for ventilation and room-conditioning systems. Even if this standard is dedicated to non-residential buildings, some reference values and guidelines are also useful for residential buildings

EN 13141 (parts 1 - 10) - Ventilation for buildings - performance testing of components for residential ventilation. Some parts of this standard are in revision, such as part 7 (mechanical supply and exhaust ventilation units including heat recovery). Part 7 has been revised concerning more detailed testing conditions for ventilation units considering combined systems including heat pumps using waste heat from exhaust air. The

EN 13141 should be more accepted from the CEN members after revision.

EN 13142:2004 - Ventilation for buildings - Components/products for residential ventilation - Required and optional performance characteristics

4.1.4 Field Study on Ventilation systems in Austria

A field study on technical status of ventilation systems in residential buildings was realised in 2002-2003 in Austria. It focused on balanced ventilation systems including heat recovery in single family houses. The project was carried out by four Austrian institutes (FH Kufstein, Energie Tirol, AEE Intec and arsenal research) and the results are documented in a report in German language [120]. The main project outcomes being also valid for residential buildings undergoing renovation activities are summarised here. Within the project, 92 ventilation systems were investigated. The goals of the project were:

1. Survey of existing solutions and assessment of commonly used design criteria for balanced ventilation systems
2. Survey of the acceptance of balanced ventilation systems

The assessment methods used were:

- Documentation of systems installed few years before the survey was done. The documentation contained characteristic figures of the system (e.g. design data, ventilation rate, kind of supply system, kind of defrosting strategy, filter quality, etc.), photos of specific solutions and parts of the system and measurement results (pressure drop, air temperatures, air change rates for each room, etc.).
- Assessment of user satisfaction with the system taking into account the results of the technical assessment. Users were asked and a questionnaire was filled out.

The main results were:

Although the satisfaction with the reached effect of mechanical ventilation was very high (about 87% of the asked users were satisfied with their ventilation systems), the systems had many defects leading to low efficiency and insufficient air quality and comfort. Some of the effects were not identified by the users, for example a higher energy consumption caused by blocked filters or missing duct thermal insulation.

One main and often mentioned problem was the disturbing sound level in the sleeping rooms. This problem can be caused by too small diameters of pipes and components, missing sound absorbers or too loud ventilation units. As a consequence the users often lower the ventilation rate or switch the ventilation system off at night.

The choice of air change rates for the rooms was not done correctly in many cases (under sizing problem). Only few documents presenting calculation results could be found. Figures and installation plans were also vary rare. This could not facilitate the work of for service personal if a problem would occur.

Many failures are related to the missing experience of installers in this technology field. On the other hand many problems are linked to the missing availability of data like consistent energy performance figures, acoustic or hygienic properties of components.

As a result of the project a draft of about 55 technical quality criteria was developed. This paper has been updated regularly considering new standards, new experiences and expert contributions from German speaking countries. The paper is available in German only on [120]

Additionally to the results of the survey based on single family houses, an ongoing project is concentrating on centralised ventilation systems in apartment buildings (presented [121]). The target of this project is to develop a general design guideline for balanced ventilation systems in residential buildings using local, semi-central und central systems.

4.1.5 General requirements for a high user acceptance

It is difficult to define standardised technical quality criteria based on a wider international level because building stocks and requirements are quite different from one country to the other. However it is possible to define general criteria that may achieve a high acceptance level of the occupants.

On the basis of the experience and field studies in Austria and Switzerland, the most important criteria generally applicable for new buildings as well as for renovation are:

- *The air change rate has to comply with the hygienic requirements:* Many problems occur when air change rate is not adapted to the variable needs of the users. Especially in cold climates with temperatures under 0°C over several weeks the indoor air humidity may drop below 30% if the air change rate is too high. On the other side, when the air change rate is too low, users mostly only notice it when they enter the room, not when they have been in the room for many hours. In many cases they may open windows when they do not have the possibility to increase the ventilation rate. Otherwise the user acceptance might be lowered.

- *The system is designed to provide the best possible air quality at the considered location:*
  Air quality is affected by several parameters like local emissions, dust or odours. Therefore it is recommended to dispose the fresh air intake at the appropriate side of the building with the right filter quality. The filter quality depends on the desired indoor air quality and the local outdoor air quality (see EN 13779). The conception of the system and the used material may also influence the indoor air quality. Additionally several hygiene formalities have to be complied to achieve a long life system (see VDI 6022): (1) keeping all components clean inside is better than periodical cleaning effort and (2) all air streamed components have to be installed in a way to be cleaned or replaced easily
- *The supply air generates no draft effect in spaces where occupants remain*
- the installation of air inlet has to take into consideration possible furniture and the common area of occupants. Also the choice of the appropriate outlet is important to avoid draft effects. The temperature of the supply air at the inlet should be above 17°C.
- *The noise from the ventilation system is not noticed in the sleeping and living areas (in some countries it may be requested to indicate whether the system is working. This requirement can be solved noiseless, using for instance luminous signals our displays.)*
- One of the most important requirements is a silent system in sleeping rooms. Also in living rooms noise should not be considered disturbing. A noisy system would not be accepted and it is difficult to reduce the noise after the system has been installed. In toilets or baths the requirements are not so high.
- *in combination with an air tight building, the ventilationsystems contribute to a major reduction of the heating energy demand when used in combination with heat recovery*
- Air tightness has to be tested to enable good indoor air quality and low energy losses. This means only high efficient ventilators have to be used. Additionally pressure drop in the ducts has to be minimised to reduce electricity demand. The ventilation unit should enable an efficient heat recovery (minimum 60% without condensation, testing conditions in EN 13141-7 for units in dwellings). Often unconsidered influence results from un-insulated cold pipes in conditioned zones or warm pipes in unconditioned zones. So pipes with heat transfer to the ambient room should be as short as possible and well insulated.
- *the installation of ventilation system is done by taking into consideration other systems dealing with air (ovens, exhaust hoods, centralised vacuum cleaners,…) to avoid dangerous situations or failures*
- To avoid low indoor pressure (more than 4 Pa difference to outside) the incoming and outgoing air mass flows have to be balanced. If ovens have an influence on the indoor air, a safety system has to prevent the suction of exhaust gas caused by unbalanced air systems. For all modern households circular cooker hoods, indoor air independent ovens and applicable ventilation units are recommended.
- *The ventilation system can be operated easily and the user can change the filter by its own if the unit is in his dwelling:*
- The number of control functions a user should have is discussed frequently. Austrian experts recommend the possibility to switch the system in minimum 2 steps to adapt the desired air quality. Lowering the air rate when users are absent should be controlled automatically by CO2-sensors or can also be realised by defining time schedules (applicable for periodical absence).
- *The ventilation system should be designed and realized by certified (skilled) planers and installers o achieve a very good cost-benefit ratio and an efficient support*
- In Austria and Switzerland a special training programme for installers was developed with the goal to raise the quality of ventilation systems. The optional personal certification is an effective marketing instrument and gives the customers a high reliability by contracting the installation of a system. Many companies offer only parts of

ventilation systems but don't provide any support. Certified installers have the task to advise their customers and offer service for the whole lifetime of the system.

- *basis for the design, realization and operation of the ventilation systems are the national norms, local requirements (e.g. fire protection) and defined technical quality criteria (55 quality criteria for comfort ventilation systems)*

The term "comfort ventilation" (from the German "Komfortlüftung") refers to a specific mechanical ventilation concept complying with specific qualitative quality criteria for residential buildings. Among Swiss and Austrian experts, it is considered to represent the ideal ventilation system in residential buildings. Since it does not refer to quantitative criteria, the term "comfort ventilation" might be used at an international level.

In practice and because of specific buildings and users characteristics, ventilation systems combine the features of central and local ventilation systems. Ventilators can be installed centrally and heat exchangers in each dwelling, or each dwelling might be equipped by individual ventilators whereas large heat exchangers might be installed at a centralised place.

4.1.6 Parameters guiding the choice of a concept for a ventilation system

The design of ventilation systems for renovated buildings highly depends on the building and user characteristics. On the other side, the design requirements and practices still strongly depends on national regulations and building codes. So it is not possible to provide general recommendations specifying for instance which type of ventilation system has to be used in which situation.

Conventional approach and proposed approach

The conventional design approach consists in considering first the eventuality of using ventilation through window openings and in a second step the possibility of mechanical ventilation units, only if required air changes can not be insured by using window openings. The proposed approach consists in changing the order in which the different alternatives are. Given the high air tightness of buildings which have been renovated, a mechanical ventilation system should be installed when possible in order to guarantee high internal air quality. If possible, a comfort ventilation system should be analysed as first alternative. If this solution can not be implemented, other solutions can be analysed (exhaust ventilation systems…). Ventilation through manual opening of windows should be considered as last solution. In an airtight building after renovation, manual window opening can neither guarantee a hygienic internal quality nor a good thermal energy performance. However, a general approach for the design of ventilation systems can be proposed as well as a list of the main influence parameters which have to be taken into consideration when designing a ventilation system in a renovation project. It is difficult to identify the relevant key parameters supporting one ventilation concept rather than one other. In many cases it is the combination of different parameters which guide the choice towards one solution rather than the other. However it is possible to describe how far single parameters can guide the choice towards one concept rather than another.

Figure 4.1-1
Leakage near the window frame evidenced by light penetration.

Ownership structure

The ownership structure in an apartment building can be determinant for the degree of centralisation of the components of ventilation systems. In co-ownerships where each flat belongs to a different owner it is difficult to think about a centralised system, mainly because of there are many incompatibilities between the ownership structure and the organisational issues linked with the implementation of a centralised ventilation system (high investment costs, responsibility for operation and maintenance etc.). Local ventilation systems are more adapted in those situations.

Maintenance effort

The effort necessary for maintaining the ventilation system is proportional to the number of filters to be regularly replaced. In an apartment building where filters are installed at the supply air duct for each dwelling, the best situation is when filters can be accessed directly from the common parts of the building, in order to avoid maintenance staff going inside the dwellings to replace old filters.

Climate conditions

Climate conditions can be decisive while choosing between individual ventilation units and a central ventilation system supplying many dwellings. Heat recovery devices (heat ex changers) have to be protected from frost. If individual units are not equipped with pre-heaters to prevent heat exchangers from frost damages, the devices should not be used, which limits the time when the rooms are ventilated. Central devices can be usually equipped with pre-heaters, so that the ventilation systems can be operated also during times with Tair<0°C.

Total costs

In buildings where renovation costs have to be kept at a particularly low level (e.g. in the social housing sector), it is not always possible to implement comfort ventilation systems (supply and exhaust systems) which are characterised by particularly high investment costs. In such conditions, humidity controlled exhaust air systems can be particularly convenient, while maintaining the energy performance of the building in acceptable levels (see publication Geneva). To control the air flow of exhaust air ventilation systems it is necessary to guarantee a particularly high air tightness of the building envelope; this is not easy to reach during renovation works.

Architectural limitations

The architectural characteristics of the building and in particular the space available for air ducts is decisive while analysing the feasibility of comfort ventilation system requiring supply and exhaust air ducts.

Size of dwellings

The size of dwellings and in particular the number of rooms (not all dwellings provide the possibility to have separated fresh air supply and exhaust air zones) are important factors while designing the ventilation system. Not all dwellings at one floor need to be equipped by the same type of ventilation system. Very small dwellings can be equipped with individual ventilation units whereas bigger dwellings can have supply and exhaust air ducts.

4.1.7 Definitions / glossary

Comfort ventilation system

A comfort ventilation system for residential buildings is a supply and exhaust ventilation system with heat recovery which is designed, realized and operated in a way to obtain maximal comfort, hygiene and energy savings. A comfort ventilation system is characterized through following points: Ventilation systems can be characterised in function of the degree of aggregation of the single components constituting the system. The terminology central/local/semi-central can be used but need to be defined carefully.

Central ventilation system

A central ventilation system consists of a central ventilation unit grouping all main components of the system (ventilators, heat exchangers and filters) at one place. For an apartment building, the central unit is connected to every single apartment through supply and exhaust pipes.

Local ventilation system

A local ventilation system consists of many distributed ventilation units installed directly in the rooms or dwellings to be ventilated. At the scale of an apartment building, it means that every apartment has its own ventilation unit.

Semi-central ventilation system

In practice and because of specific buildings and users characteristics, ventilation systems combine the features of central and local ventilation systems. Ventilators can be installed centrally and heat exchangers in each dwelling, or each dwelling might be equipped by individual ventilators whereas large heat exchangers might be installed at a centralised place.

4.1.8 References

[120] PROJECT: Technical status of ventilation systems for buildings; Austrian Program on Technologies for Sustainable Development, funded by “Federal Ministry for Transport, Innovation´and Technology” (BMVIT), 2004 Project leader: FHS-Kufstein Tirol
more information:
http://www.hausderzukunft.at/results.html/id2804

[121] Web site on comfort ventilation systems, more information:
www.komfortlüftung.at

4.2 Hybrid ventilation

Jan Hansen, Olaf Bruun Jørgensen

In the following a description of concepts for hybrid ventilation and an overview of state-of-the-art systems are presented.

This chapter is primarily based on the experiences and results obtained in the EU-project "RESHYVENT, Cluster Project on Demand Controlled Hybrid Ventilation in Residential Buildings with Specific Emphasis on the Integration of Renewables", Contract No: ENK6-CT2001-00533. [124][125]

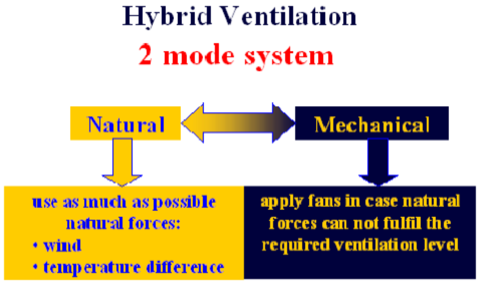

Figure 4.2-1
Illustration of the principle behind hybrid ventilation. Source: [1]

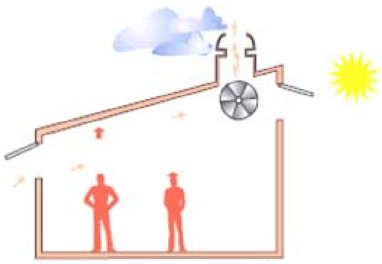

Figure 4.2-2
Principle sketch of the hybrid ventilation concept

4.2.1 Introduction

Ventilation accounts for approximately 10% of the total energy use in EU. It is therefore important to provide energy efficient ventilation concepts based on demand control, hybrid technologies, and integration of renewables.

In the EU project "RESHYVENT" four hybrid ventilation concepts for different climate zones have been developed

In an on-going Danish energy research project "Natural Ventilation with Heat Recovery and Cooling" a new heating and ventilation concept is being developed.

In another Danish business post graduate project a so-called passive ventilation system with heat recovery and night cooling is being developed.

In the following the above mentioned projects and concepts are described further.

4.2.2 Definition of hybrid ventilation

Hybrid ventilation is a two-mode system which uses both natural and mechanical driving forces.

Within hybrid ventilation three ventilation concepts can be defined:

- Alternate use of natural and mechanical ventilation
- Fan assisted natural ventilation
- Stack and wind supported mechanical ventilation

A control system has to establish the desired air flow rate and pattern at the lowest energy consumption possible while maintaining acceptable indoor air quality and thermal comfort conditions. This means:

- air flows will be accurately controlled to actual needs, based on thermal comfort and indoor air quality;
- Using natural driving forces as long as possible, using mechanical forces when necessary.

The principle is illustrated in Figure 4.2-1and a principle sketch can be seen in Figure 4.2-2.

The two modes, natural and mechanical forces are combined and alternated between to maintain a satisfactory indoor environment and at the same time saving energy and money to the year-round use of mechanical ventilation. The current mode of the ventilation system reflects the external environment and takes maximum advantage of ambient conditions at any point in time. Therefore the operating mode varies according to the season and within individual days.

4.2.3 Hybrid ventilation systems developed in RESHYVENT

In the EU-project *RESHYVENT* four hybrid ventilation systems have been developed for different European climates zones: mild and warm, moderate, cold, and severe climate zones.

There has been specific emphasis on the application of renewable in combination with the hybrid ventilation systems. Auxiliary energy is needed for running the fans, the sensors and the control system, and the aim was, as far as possible, to generate the needed energy by sustainable technologies, such as PV and wind energy.

The four hybrid ventilation concepts are presented in the following.

Severe climate

A hybrid ventilation concept for extreme cold climates has been developed by a Norwegian industrial consortium.

For these climate conditions heat recovery is necessary for preheating and to recover energy. In the Norwegian concept hybrid (natural) ventilation is combined with heat recovery. In Figure 4.2-3 and Figure 4.2-4 principle sketches of the system are illustrated.

A supply system with low-pressure ducts is used. The heat recovery system consists of a rotating heat exchanger, see Figure 4.2-5.

Special attention has been paid to develop and optimize the outlet with wind vane and the air inlet on top of the roof. The air flow is controlled with CO_2-sensors as well as with RH-sensors. The system has been tested in four demonstration houses in several configurations and has been extensively monitored and tested under occupied conditions, see Figure 4.2-6 based on measurements and experiences the system was later modified with respect to automation and noise reducing measures.

The system was not put in series production and is not today commercially available.

Cold climate

A hybrid ventilation concept for cold climates has been developed by a Swedish industrial consortium and this concept addresses apartments in cold climates.

As the ventilation demand in these climates often corresponds with the heat demand, the ventilation supply is integrated in a combined hybrid supply convector. Air collectors can preheat supply air. Next to this, it is possible to preheat the air partly by a solar collector. The exhaust system is a fan assisted passive stack system.

Communication with the occupants via the internet about the energy performance of the system is one of the developments of the Swedish system, see

The ventilation concept is based on an exhaust air system with low pressures drops and a separate fan for each apartment. The fan has a built-in control system for a, according to desire, adjustable constant

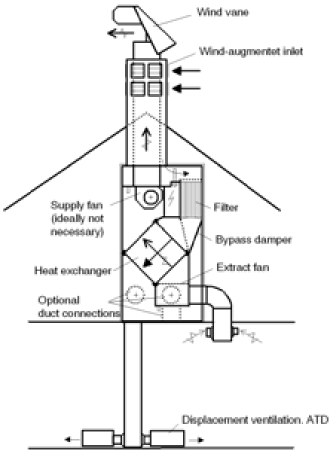

Figure 4.2-3
Principle sketch of the Norwegian system

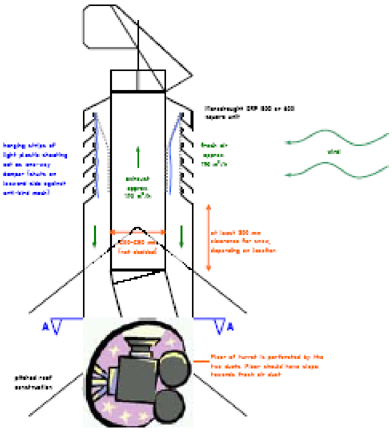

Figure 4.2-4
Principle sketch of the Norwegian system

Figure 4.2-5
Rotating heat exchanger

Figure 4.2-6
One of the test houses

Figure 4.2-7
Communication with the occupants via the internet

exhaust air flow independent of the boundary conditions. The desired normal air flow can be set, according to the size of the family, from a panel in the apartment, but is also automatically controlled by humidity and outdoor air temperature. The outdoor air is preheated by a supply convector. Each apartment has individual control of indoor climate and individual metering of energy use. In Figure 4.2-8 a principle sketch of the system is illustrated and in Figure 4.2-9 the ventilation control panel for the occupiers can be seen.

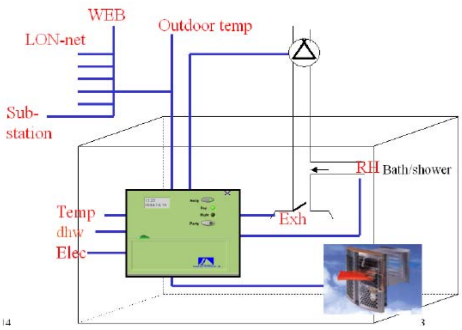

Figure 4.2-8
Principle sketch of the Swedish system

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Figure 4.2-9
Ventilation control panel for the occupiers

As to the application of renewable energy the following was concluded:

- The costs of solar photovoltaic cells for operating the fans are still too high to be of interest.
- Integration of wind cowl, might be an interesting application
- Integration of small wind turbine, might be an interesting application in the future
- Solar air collector for pre-heating of inlet air is possible but not very feasible due to the low air flows.

Investigations of draft risks were also performed and in Figure 4.2-10 the air flow through the supply convector is illustrated. Analyses and simulations of an entire building with the system show that the system fulfils the performance specifications and is likely to fulfil the expectations of the customers. The system will result in a similar level of energy use for space heating as for a system with balanced ventilation with conventional heat recovery, but lower use of electricity, more user-friendly and improved indoor air quality. The calculated savings compared to standard ventilation technology shows for the fans that the concept meets the same level of specific efficiency electricity use (0,5 kW/m^3/s), but the reduced air flow thanks to demand control will reduce the average electricity needs. After the completion of the RESHYVENT project a full-scale demonstration of the system in a real building was planned. Unfortunately, this has not been carried out yet.

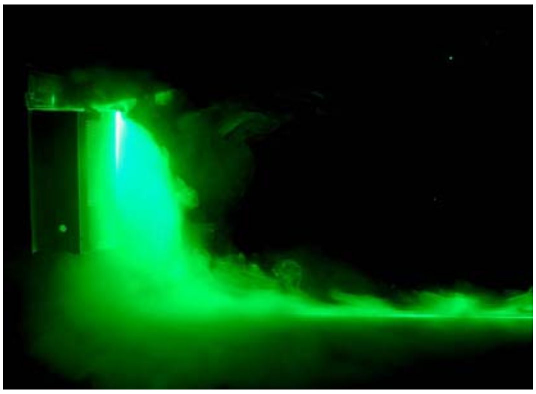

Figure 4.2-10
Figure of the test with smoke and laser visualization

Moderate climate

A hybrid ventilation concept for moderate climates has been developed by a Dutch industrial consortium. This concept addresses dwellings and apartments.

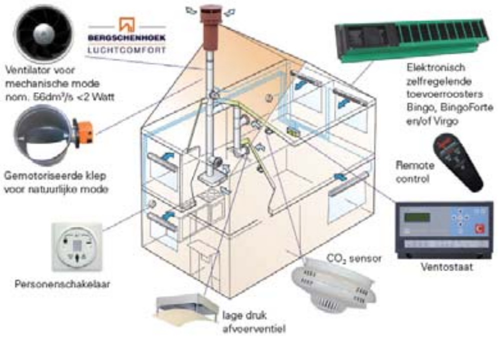

Figure 4.2-11
Principle sketch of the system

Figure 4.2-12
Illustration of the low pressure exhaust

The Dutch concept is a fully hybrid demand controlled system with de-central supply from the façade and a coupled hybrid central mechanical extract. The principle is illustrated in Figure 4.2-11.

Air flows are controlled by CO$_2$-sensors in habitable rooms. In Figure 4.2-12 the sensor controlled air inlets can be seen. In Figure 4.2-13 the principle behind the self-regulating air inlets is illustrated and in Figure 4.2-14 a components sketch of the inlets and CO$_2$-sensors can be seen. A characteristic development in this concept is an extreme low-resistance ductwork (< 2 Pa at 56 dm^3/s) based on the experiences and components developed within the EC TIPVENT project. A special fan was developed using 2 Watt at 56 dm^3/s at 20 Pa. This extreme low fan power is possible by a combination of the low pressure duct work and optimized wind cowls (<1 Pa at 56 dm^3/s), see Figure 4.2-15. Supply grilles are actively controlled with compensation for cross flow and infiltration. The prototype was tested in 2003 in laboratory and in 2004 the system was integrated in a newly build test house at Brno University of Technology, Czech Republic and was extensively tested, see Figure 4.2-16. The work led to a commercially available system which since 2005 has been available on the market in 2005 ("Vent-O-Hybrid", www.alusta.com), see front page of brochure in Figure 4.2-17.

Mild and warm climate

A hybrid ventilation concept for mild and warm climates has been developed by a French/Belgian industrial consortium: This concept addresses dwellings. The French/Belgian consortium worked on the integration of renewables (i.e. PV application) in combination with hybrid ventilation. Like the Dutch concept, this concept is also based on a fully hybrid demand controlled system with de-central air supply from the facade and a coupled hybrid central mechanical extract. Air flows are controlled by IR- and motion detection sensors in habitable rooms and RH sensors in wet rooms. In Figure 4.2-18 and Figure 4.2-19 an overview of the components and the principle of the French/Belgian concept can be seen.

Measurements were carried out for the hybrid ventilation system and in Figure 4.2-20 selected results of the measurements are illustrated.

PV provides the auxiliary energy for the fan. There is special attention for the summer comfort in the application of free cooling during the night.

A fan was developed that can be used for combined natural and mechanical exhaust ventilation. In Figure 4.2-21 some characteristics of the fan are illustrated. Power consumption of the fan is only 2 W and there are no pressure losses when the fan is off. Elements from the French/Belgian system are commercially available from the company Aereco (http://aereco.com/).

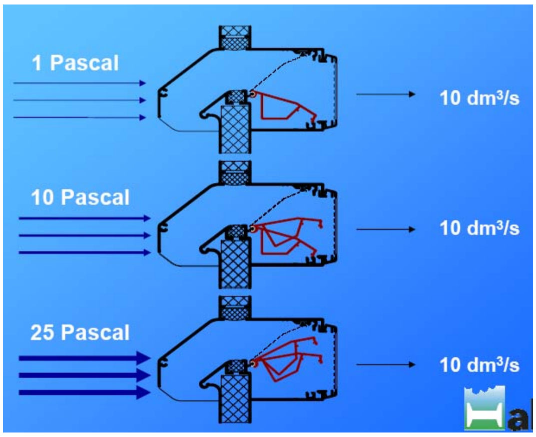

Figure 4.2-13
Self-regulating inlets

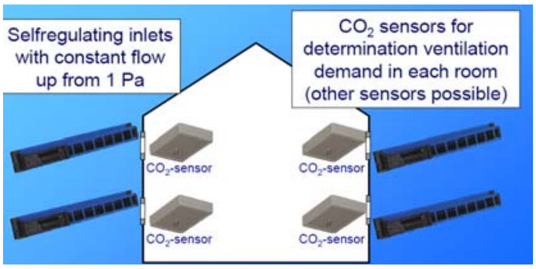

Figure 4.2-14
Sensor controlled air inlets

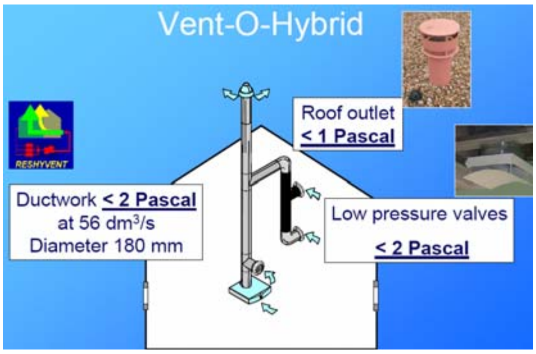

Figure 4.2-15
Components sketch of inlets and CO$_2$-sensors

Figure 4.2-16
System integrated in test house at Brno University of Technology, Czech Republic

4.2.4 NVVK, Denmark

In Denmark in 2006 the energy research project "Natural Ventilation with Heat Recovery and Cooling" was initiated. A new heating and ventilation concept has been developed where the heat energy from the extract air in natural ventilation is being recovered for space heating and domestic hot water.

Besides, it is possible to cool the inlet air and use the thermal energy for heating of domestic water. The energy from cooling is in this way exploited in stead of being let out to the surroundings which usually is the case. The project proved with theory and laboratory experiments that savings of up to 25% both in energy consumption and operational costs can be achieved compared to the best heating and ventilation systems on the market for the time being. Further details on the concept will not be described here as the developers do not wish to make specific information public. It is expected that a system based on this concept will be commercially available from mid-2011. The concept is now being implemented as a full scale demonstration project in a sports centre in Denmark, see Figure 4.2-22.

4.2.5 Passive ventilation systems with heat recovery and night cooling, Denmark

Development of a so-called passive ventilation system with heat recovery and night cooling is now being performed as a business post graduate project co-operation between Alectia A/S and the Technical University of Denmark. Passive ventilation in this context means ventilation solutions that exploit natural driving forces and the building envelope physics to establish and maintain a satisfying indoor climate without the use of electricity. The concept is based on using passive measures like stack effect and wind driven ventilation, effective night cooling and low pressure loss heat recovery using two fluid coupled water-to-air heat exchangers developed at the Technical University of Denmark. The ventilation system has an intake of fresh air at ground level and exhaust above the roof. The duct system consists of large main ducts for intake and exhaust. Via a

Figure 4.2-17
Front page of brochure for the ventilation system.

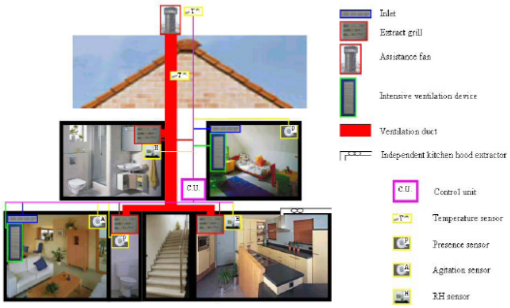

Figure 4.2-18
Various components of the hybrid ventilation

Figure 4.2-19
Overview of the hybrid ventilation system

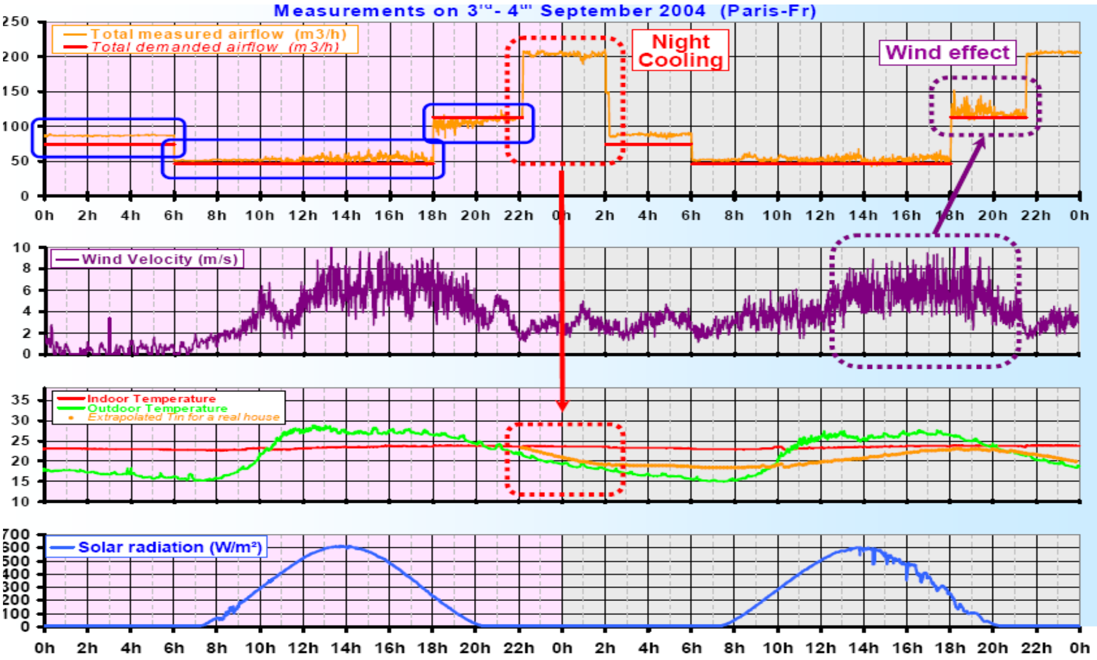

Figure 4.2-20
Selected results of the measurements

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diverging duct, smaller supply ducts feed fresh air to the work-spaces that are situated vertically above each intake. Exhaust ducts from each work-space extracts the stale air and via a converging duct and a large main duct the air is exhausted to the outside. Figure 4.2-23 shows the schematic layout of the system. [122]

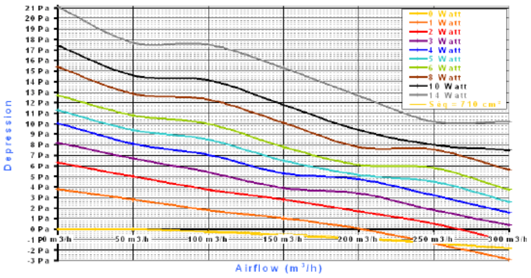

Figure 4.2-21
Characteristics of the fan

Figure 4.2-22
New sport centre in Denmark with the ventilation concept (Stuff Aps)

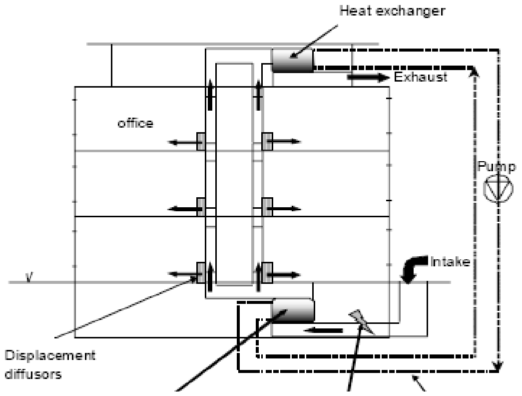

Figure 4.2-23
Schematic layout of the passive ventilation system

Figure 4.2-24
Developed heat exchanger at an exhibition

The design of the heat exchangers in the ventilation system is a crucial factor. There are two primary objectives for optimum performance that governs the design of the heat exchanger:

- Low frictional loss on the air side
- Effective heat transfer area

The exchanger is constructed from 8mm plastic tubes commonly employed in water-based floor heating systems. This makes the exchanger relatively compact while keeping material costs low. In Figure 4.2-24 a photo of the developed hest exchanger can be seen.

The pressure loss of one exchanger has been measured to 0.37 Pa and a directly measured temperature exchange efficiency of 75.6% for a design airflow rate of 560 l/s. The experimental results agree well with various literature sources or numerical fluid calculations. The total pressure drop of two liquid coupled exchangers is 0.74 Pa and the total heat recovery is calculated to be in the range 64.4–74.9%. The range is a depending on the parasitic heat loss in the experimental setup. Following the analytical framework preliminary improvement calculations promises a future efficiency of 80% with a pressure drop of 1.2 Pa. [123] Simulations performed in [122] indicate that passive ventilation has larger potential compared to conventional mechanical ventilation. In conjunction with adequate night cooling both ventilation and cooling tasks are performed satisfactorily. Consequently energy consumption for fans and mechanical cooling can be saved in a passive ventilation system. If the system is equipped with low pressure loss heat recovery and electrostatic filtering it may perform the task of ventilation, cooling and heating in high performance offices with comparable flexibility and total costs to that of conventional mechanical systems.

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4.2.7 Ventilation concepts for Passive Houses

4.2.8 Types of ventilation

Berthold Kaufmann, Witta Ebel

For the occupants the most important planning aspects are health and comfort. Excellent air quality is especially essential and can only be achieved if “used” air is regularly replaced by fresh air. Opening windows twice a day is not enough, see below. Comfort ventilation based on the requirements for fresh air is therefore indispensable in every Passive House and similarly renovated buildings.

A regular, guaranteed and adequate exchange of air in winter is only possible by means of comfort ventilation – this also applies for ordinary new buildings. The issue here is not energy efficiency, but the health of the building's occupants; Indoor Air Quality (IAQ) has a much higher priority than energy conservation – but it turns out that there is no conflict at all, if efficient components are used.

Purge ventilation through windows

Without comfort ventilation, adequate air exchange in new buildings can only take place by means of regular purge ventilation. In order to achieve an air exchange of about 0.33 ach (air change per hour), one would have to open the windows wide for 5 to 10 minutes every three hours – even at night! This is rarely done in practice.

Accordingly, the air quality is usually poor and there is an increased risk of high air humidity. Because we cannot perceive the indoor air quality ourselves and it is not possible for us to estimate the amount of fresh air actually supplied through open windows, it is difficult, even for an expert, to achieve “just the right” amount of air exchange.

- If ventilation is insufficient, the air quality will be poor and there will be a risk of condensation occurring.
- If too much ventilation takes place, the air will become too dry and energy consumption will become excessively high.

One of the reasons for home ventilation is to reduce the air humidity in the home slightly, because a high level of moisture in the air often causes building damage. However, the air should not be too dry either.

The right level of air humidity is not the only requirement for an adequate exchange of air. Pollution of indoor air, due for example to the radioactive inert gas Radon, must be reduced to safe levels by adding fresh air.

Why opening the windows twice a day isn't enough

It's quite simple:

- If the window is opened wide for long enough, the stale indoor air will be replaced by fresh outdoor air.
- When the air replacement is complete, the windows don’t need to be kept open any longer (replacing of fresh air with fresh air?).
- Window ventilation provides this kind of just one complete air exchange each time it takes place.
- If this is done twice a day, this means two air replacements in 24 hours or an average air change of $2 / 24\ h^{-1} < 0.1\ h^{-1}$.
- There is no doubt that 0.1 air exchanges per hour is insufficient for good health and comfort (see following illustration).

Why is an adequate supply of fresh air so important?

Moisture and CO_2 for typical living situations is continuously being released into the room, especially at night.

- If the air is not replaced, the relative air humidity increases – these periods of increased humidity can be seen clearly.
- One can also see that each time the window is opened for airing, the humidity level drops (valleys). The residents open the windows for airing more than twice a day - but in spite of that the humidity keeps increasing and for long periods of time it remains above 60%.
- The green curve shows the indoor air humidity near the inner surface of the external wall. A relative air humidity level of more than 80% is often present here. These are the conditions which encourage mould growth (area in blue).

Conclusion: The overall air exchange achieved for this measurement is inadequate; more ventilation is required in order to remove the moisture in the room air.

The effects of insufficient air exchange rates are mainly based on the concentration of water vapour (humidity). Water vapour is neither the only nor even the main impurity in indoor air. **CO_2**, Radon, volatile organic

Figure 4.2-25
Craftsmanship is as essential as materials, evidently lacking here.

substances, dust, and many other (toxic) substances are also present in indoor air. An insufficient supply of fresh air increases the concentration of these substances to unnecessarily high levels. An adequate exchange of air is not only a question of comfort but is also a prerequisite for healthy living conditions.

For more details see the following section.. There are explained the results out of observations of air exchange rates and correlated indoor air quality in buildings with only window ventilation. [137][Kah/Ebel 2010]

How often should the windows be opened?

Well, the answer to this is difficult: the general conditions, size of windows, location of the house etc. vary in individual cases. The best solution is a ventilation system which always ensures an adequate supply of fresh air.

Because most people don't yet have comfort ventilation in their homes, we have also studied minimum ventilation through opened windows. This was done in a systematic scientific analysis which has been published in the Protocol Volume for the Working Group Number 23. This analysis showed that for adequate air exchange in a house without a ventilation system, windows have to be opened at least 4 times a day for purge ventilation - and at the largest possible time intervals, preferably in 6-hour intervals [127][Feist 2003]. That is our recommendation for all the users of homes which do not yet have a ventilation system.

This doesn't apply to residents of Passive Houses: they don't have to bother about opening the windows at the right time; of course they may open the windows if they want to – but they don't have to remember to do it regularly.

4.2.9 The simplest solution: exhaust air ventilation system

Berthold Kaufmann, Witta Ebel

The function of comfort ventilation is to supply fresh air in “just the right“ quantities to the living space. The simplest solution is an exhaust fan system that extracts the stale and humid air from the kitchen, bathroom and toilet. At the same time, fresh air (cold air in winter) is drawn in through outdoor air inlets into the living areas.

These simple systems are now standard in France; exhaust systems have been used in Sweden for more than 50 years and since 1980 it has become obligatory to have home ventilation. In Germany this could be an effective solution for new constructions built to EnEV standard and for refurbishment of existing buildings (which have now become more airtight), but unfortunately this has not been made compulsory.

For the Passive House, however, this simple system can't be considered, because the incoming air is cold and the ventilation losses will therefore be too high (see thermo graphic image). For one thing, a correspondingly high output heat supply near the inlet will then be necessary and for another, the annual heating demand will be at least double that of a Passive House. Less ventilation doesn't come into question because energy conservation should not mean less hygienic conditions.

4.2.10 Mechanical ventilation with heat recovery

Berthold Kaufmann

Controlled ventilation

Systematic examination of homes has shown that proper distribution of fresh air in all rooms and safe dehumidification of kitchens and bathrooms is possible through controlled ventilation.

- In this way the fresh air is directly supplied to the living room, office and bedrooms. These rooms are equipped with at least one supply air inlet.
- As in exhaust air systems, the kitchen, bathroom and toilet as well as other areas with high humidity and odours are ventilated directly through the extract air outlets.
- There is a directed flow throughout the house: the fresh air first enters the main living rooms (see illustration), from here it flows through the transferred air zones (usually corridors) into the humid areas. The humid areas have relatively high air changes so that e.g. towels can dry more quickly.

The convenient solution: supply and exhaust air systems with heat recovery

Ventilation will only work properly if used air is continuously being removed from the kitchen, bathroom, toilet and other rooms with high pollution and humidity. In return, fresh, unused external air is supplied to the living room bedrooms and functional rooms.

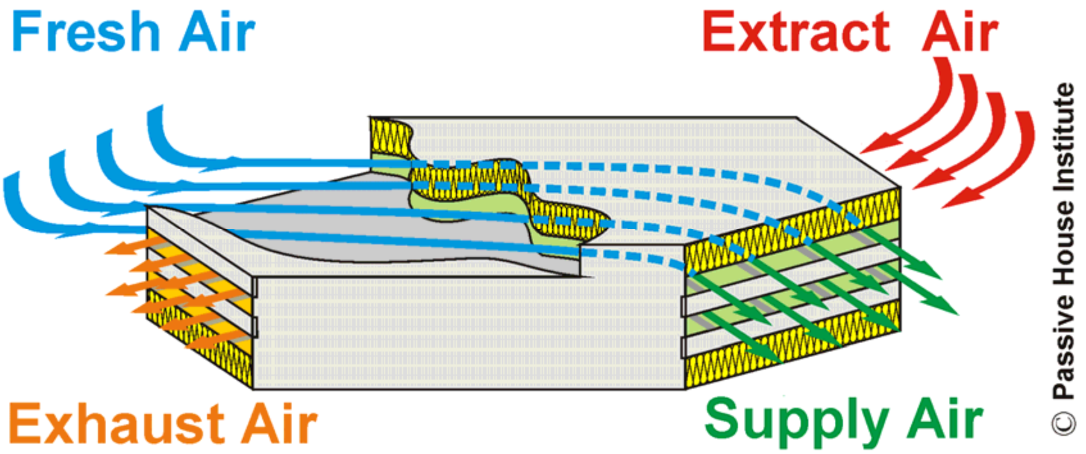

Figure 4.2-26
This is how a heat exchanger works: The stale extract air (red) flows through a duct and transfers its heat to the plates above and below. It cools down and exits as exhaust air (orange). Unused fresh air streams in through separate ducts on the other side of the plates. It takes up the heat and is available as warm (but still unused) supply air (light turquoise). The counterflow principle makes up for almost 100% of the temperature difference. Saving energy by using heat recovery is not only cost-effective and environmentally friendly but also healthy – fresh air is provided constantly without having to keep opening the windows. This applies for all buildings, not just for Passive Houses.

Just the right quantities of fresh air that are required for the good health and comfort of the occupants are supplied. Only untreated air enters the living areas, there is no re-circulated air, thus providing a hygienic air quality.

Ventilation can also take place if a simple exhaust air system and external air inlets are used. The external air inlets let fresh (cold) air in the required amounts into the rooms. However, for the Passive House the ventilation heat losses that would be caused by the disposal of the unused extract air would be much too high. It would only be possible to adjust the energy balance with a high heating output.

In cold climates Passive Houses only work if a highly efficient heat recovery system is also present. This recovers the heat from the exhaust air and using a heat exchanger, transfers it back into the supply air without mixing the air flows. Today, modern ventilation technology allows a heat recovery rate of between 75 and 90 %. This is possible due to counter flow heat exchangers and special energy-efficient fans (with so-called EC

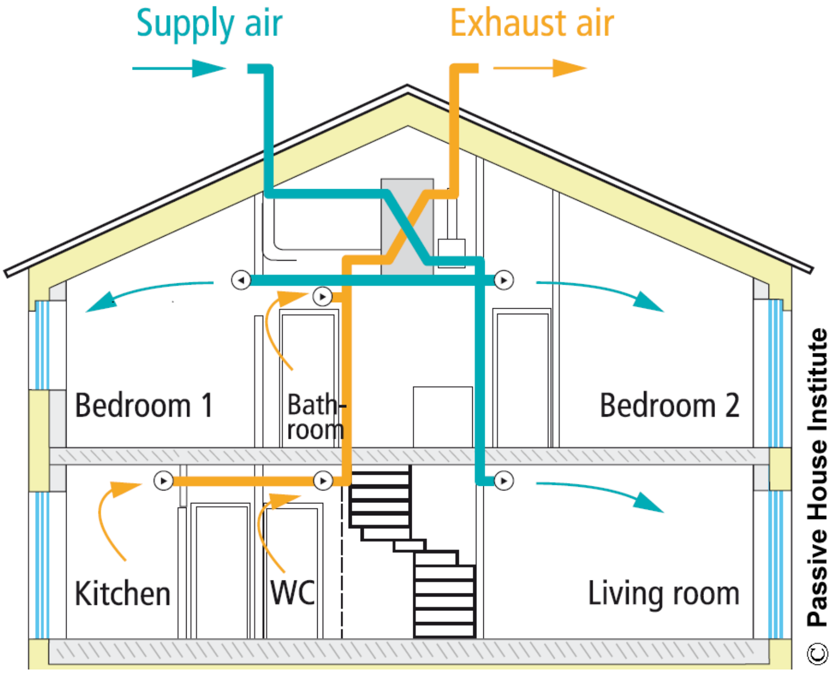

Figure 4.2-27
The principle behind convenient home ventilation: used air (brown) is continuously being removed from the rooms with high levels of pollution and humidity. Fresh air (light blue) is supplied to the living areas. Good quality air is an important prerequisite for a healthy and comfortable living climate.

motors with a particularly high effectiveness), so that the recovered heat is 8 to 15 times the electricity consumed.

Due to this principle of directed air flow, the fresh air is optimally utilised: it provides high quality air in the living areas, removes any bad air from the transferred air zones (e.g. odours from clothes), and finally dehumidifies the humid areas.

Supply air and exhaust air ducts allow the heat from the extracted used air to be recovered. The ventilation heat loss without heat recovery is between 20 and 30 kWh/(m²a) in apartments with adequate ventilation. This is very high in comparison with all other heat flows in the well insulated Passive House.

This highly efficient heat recovery system was specially developed for use in Passive Houses. The devices ensure the separation of exhaust air and supply air, don't consume much electricity and are very silent.

With such a heat recovery system, the remaining ventilation losses are insignificant: they are only between 2 and 7 kWh/(m²a), which are a good prerequisite for a functioning Passive House.

Thus, due to the heat recovery, the temperature of the supply air is raised to near room air temperature; therefore the air entering the room is not "cold" any more. Together with very good insulation of the building envelope and the windows, it is possible to get along with very little heating power and also reduce the effort for installation.

An exclusive advantage of the Passive House is that heating using the supply air is possible. Because the fresh air is supplied to the living room, bedrooms and workrooms in any case, this air can also be used to provide warmth. Because it is fresh air (not re-circulated air), the quantity of this fresh air is limited (because otherwise the air will become excessively dry), and as its temperature may not be increased too much, the supply air heating method functions only for houses with a very small heating demand – i.e. Passive Houses. Therefore, it is possible to provide very elegant and space-saving building services solutions, like the compact ventilation unit.

The highly efficient ventilation units developed for the Passive House have also proved to be effective in modernisations of existing buildings. Here they contribute to the improvement of the air quality, and ensure that mould growth does not occur at weak points in external building components, as well as helping to save energy.

An additional possibility for improving the efficiency of ventilation systems is offered by the subsoil heat exchanger: on average, the ground is warmer in winter than the surrounding air, and colder in summer. Fresh air can therefore be pre-heated or pre-cooled using the earth. This can take place directly through air ducts (air-to-soil heat exchanger) or indirectly by means of a hydraulic system (brine-carrying subsoil heat exchanger).

In hot climates, air-to-air counter flow heat exchangers can also help to recover "cool temperature" from the exhaust air and to reduce the temperature of the supply air, if the fresh air is uncomfortably hot. But this requires low energy fans in order to reduce heat loads caused by the ventilators. Humidity recovery, which is possible with special types of heat exchangers, is another highly efficient option in extreme cold and/or extreme hot and humid climates.

4.2.11 Conclusion

Passive Houses and similar renovated old buildings always have an integrated home ventilation system with heat recovery, and often this is the central component of the complete building services. Only high quality ventilation technology is suitable for the Passive House. Apart from a high heat recovery rate, low electricity consumption, and hygienically faultless and very quiet operation must be guaranteed.

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4.3 Experience and measurements from renovation projects with and without mechanical ventilation systems with heat recovery

Oliver Kah, Witta Ebel, Berthold Kaufmann

4.3.1 Introduction

Within the framework of IEA Task 37 detailed measurements of the air change rate and the air quality (CO_2 concentration) were performed in two adjacent and geometrically identical apartment buildings: Renovation Project Hoheloogstrasse in Ludwigshafen, Germany, see Figure 4.3-1 [140][Peper / Feist 2008]. The results of the detailed measurements within IEA Task 37 are published in [137][Kah/Peper/Ebel/Feist 2010].

One of the buildings (Figure 4.3-1 left) was renovated according to Passive House concept and therefore mechanical ventilation systems with highly efficient heat recovery were installed. As could be shown clearly, the air change rate (0.48 / h) in this part of the building was high enough to assure good hygienic air quality all the time. The other buildings, Figure 4.3-1 right, was intended to be renovated as a low energy building in which only ventilation via windows, opened by the inhabitants is possible. The building envelope on the other hand was realized in much better quality than German building code and therefore the building turned out to be a quite good 'low energy building' [140][Peper/Feist 2008].

In the framework of this investigation the air change rate in apartments with only window ventilation could be checked with tracer gas measurements. The measurements show in addition, that roller shutters and curtains in front of window openings have a significant influence on the overall air change rate in apartments with only window ventilation. With the measurements in real apartments of the renovated building, theoretical algorithms to calculate air change rates from window opening frequencies, measured by electrical contacts at windows, could be checked and verified.

Figure 4.3-1
Renovation project Hoheloogstraße. Left: original building, right: after modernisation in 2006 [Peper/Feist 2009].

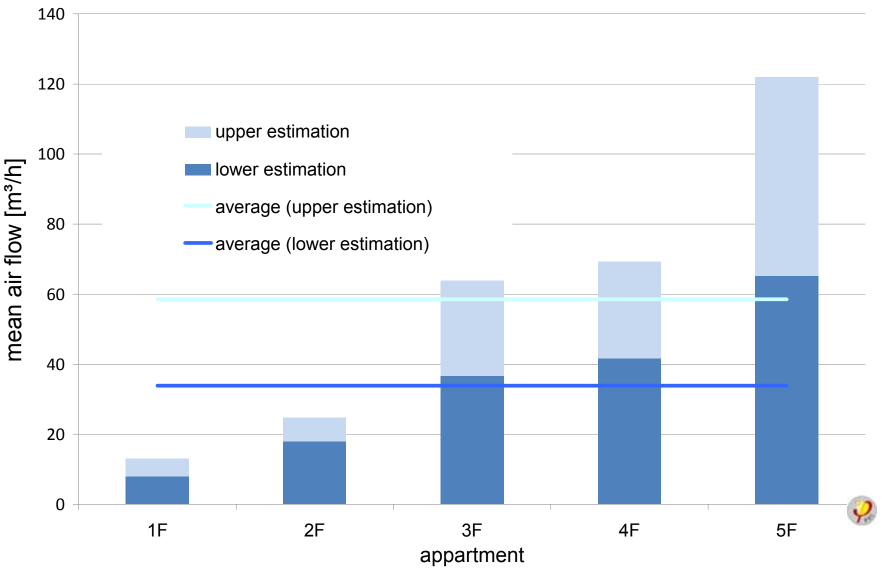

Figure 4.3-2
Average outside air flow in appartments with only window ventilation (F). With the assumptions of upper and lower estimation the average air flow in this five appartments is 59 m³/h and 34 m³/h respectively.

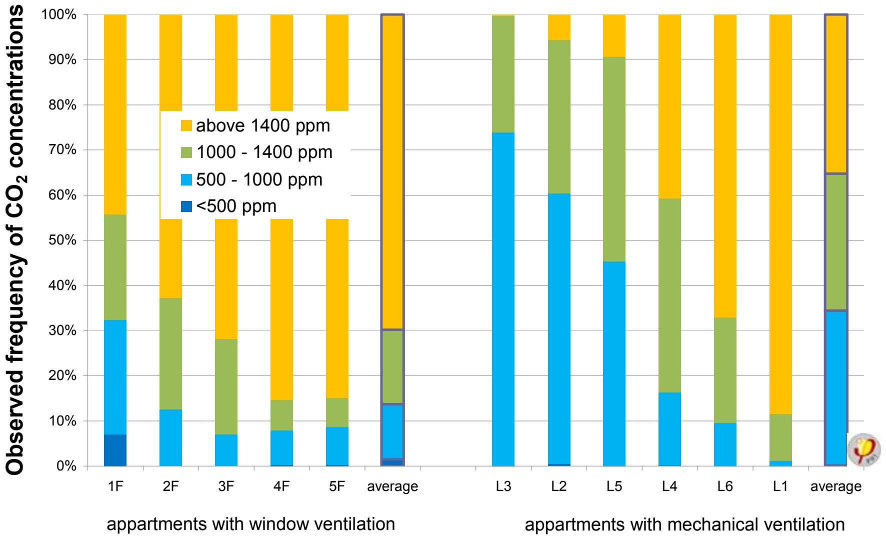

Figure 4.3-3
Statistical frequency of CO_2 concentration sorted by classes of concentration in the observed appartments during the period of monitoring (Dec 2009 to March 2010).

The frequency of bad air quality (high CO_2 concentration) is much lower in appartments with mechanical ventilation. In those appartments only during 34 % of time observed CO_2 concentrations higher than 1000 ppm were present.

4.3.2 Measurements

During the coldest time in winter from December 2009 to February 2010 the overall outside air change rate could be measured in both buildings in comparison: the one with mechanical ventilation (Passive House Renovation) and the other with only window ventilation (low energy building). During that period, data about the air change rate in five apartments with only window ventilation and six apartments with mechanical ventilation were collected. As it is rather complicated to check for all influences on the air change rate of window ventilation, an upper limit value and a lower limit value for the outside air exchange rate was calculated from reasonable assumptions.

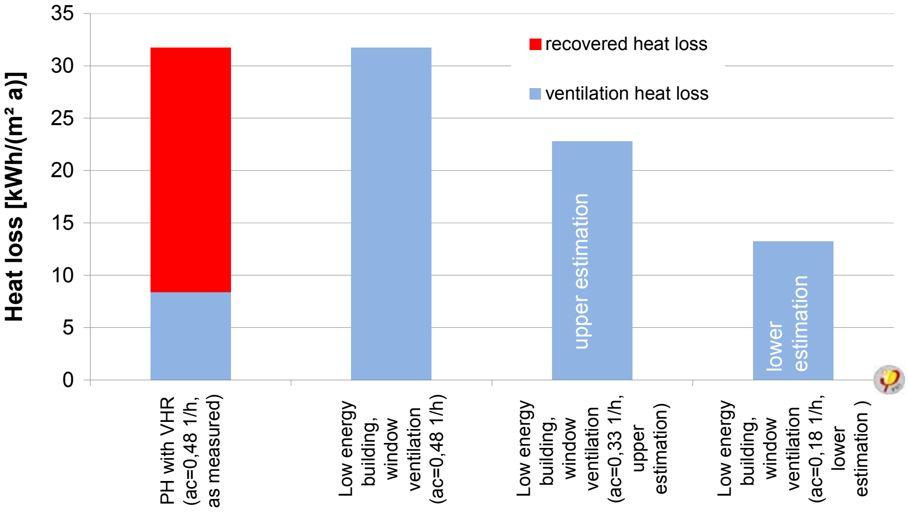

Figure 4.3-4
Comparison of ventilation heat losses of the two buildings Hoheloogstrasse: Passive House (with mechanical ventilation with heat recovery, left) and low energy building (only window ventilation, right). Shown are the average ventilation heat losses based on measured air change rates. In the apartments with mechanical ventilation, the losses are drastically (-80 %) reduced by the heat recovery (left two columns). The right two columns show the ventilation heat losses in the low energy building (upper and lower estimate) which occur if the measured but too low air exchange rates there are accounted for. Calculation done with climate data Ludwigshafen.
If the air exchange rate, needed for good air quality, is accounted for in the low energy building (2^nd^ left column) the heat energy savings by ventilation heat recovery in the Passive House part are about 23 kWh/(m²a).

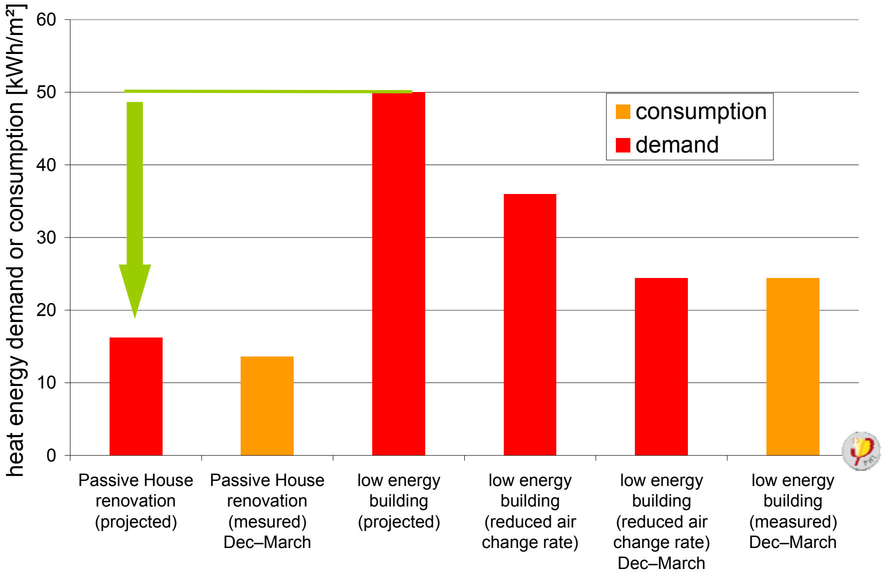

Figure 4.3-5
Comparison of measured heating energy consumption (orange) and calculated heat energy demand of the two buildings Passive House (left) and low energy building (right) Hoheloogstrasse.

The calculated heating energy demand and the measured consumption for the Passive House part match very well. As soon as the lower air change rate in the low energy building is accounted for, the heating energy demand and the measured heating energy consumption for three months (December 1st to March 1st) match very well, too.

The investigation shows, as was expected in advance, that the overall air exchange rate in apartments with only window ventilation differs very much from one apartment to another. The lowest average air exchange rate differs from the highest by a factor of about 10. In addition, the user behaviour with respect to ventilation highly varies from day to day. The average air exchange rate over all checked window ventilated apartments varies between 0.18 /h (lower estimated limit value) and 0.33 /h (upper estimated limit value), Figure 4.3-2. If the Christmas holiday's period with higher ventilation rates is excluded, the values decrease even more 10 %. In comparison: the average overall air exchange rate in the apartments with mechanical ventilation was measured to be 0.48/h.

In addition, the measurements of air quality demonstrate that the conditions in the apartments with mechanical ventilation are quite better. In the apartments with only window ventilation the air quality was critical (CO_2 concentration higher than 1400 ppm) for more than 70 % of the observed time period. In all apartments with mechanical ventilation, this was observed only for 34 % of the monitored time period (Figure 4.3-5). Even worse are the conditions during those times when people are typically present in their apartments e.g. at night. In sleeping rooms with only window ventilation the times with bad air quality raise to 81%. For rooms with mechanical ventilation this is the case only for 44% of the total time. The ventilation systems in one of the observed apartments suffered of functional disorder and therefore the supply air flow was lower than designed. If that had been repaired during the time of observation, the results there would have been even better.

Earlier investigations [140][Peper/Feist 2008] showed as well heavy differences of the user behaviour with respect to ventilation frequency. The present monitoring of air exchange rates in this building supports the assumption that in apartments with only window ventilation people open windows rather rarely and thus there is not enough air exchange to ensure good air quality. The measured occurrence of opened windows in this study are on the other hand similar to measurements published earlier [143][Reiß et al. 2001], [135][Hausladen et al. 2003], [132][Ebel/Kah 2003]. These results lead therefore to the assumption that the so called 'natural ventilation' can only provide air exchange rates which are lower in practice than needed according to current hygienic requirements. This observation supports the recommendation that for current buildings a mechanical ventilation system is absolutely necessary to ensure hygienic air quality [134][Feist 2004].

4.3.3 Ventilation and energy consumption

Another fact of the monitoring should be mentioned in this context. The heat energy consumption was monitored in parallel from December 2009 to March 2010 in both buildings.

At the Passive House renovation, thus in the building with mechanical ventilation, the monitored energy consumption during the observed period was in good accordance to the energy balance calculation (PHPP) done during planning. The heat energy consumption from December 1st to March 1st was measured to be 13.6 kWh/m². An extrapolation to the total heating period using monthly values out of the energy balance calculation shows that this is quite good compatible to the calculated heating energy demand of 16.2 kWh/(m²a) for this part of the building.

On the other hand the heat energy consumption of the apartments of the low energy building part with only window ventilation was significantly lower than the values for heat energy demand out of the energy balance calculation. The measured heat energy consumption turned out to be only 24.4 kWh/m² during these three months.

The solution for this mismatch is found when the ventilation heat losses are taken into account. As explained above, the actual measured air exchange rate in this apartment is by far lower than needed and recommended one for hygienic air quality. The theoretical heat energy balance calculation on the other hand uses the higher air flow and thus the ventilation heat losses are much higher for window ventilation without heat recovery. The higher heat losses at higher air exchange rate (Figure 4.6.4) would raise the heat energy consumption of the low energy building from 24 kWh/m² during these three months to a value of about 36 kWh/m² for the same period of the winter. If this three-month-value is taken and extrapolated to the whole heating period – which is possible e.g. with the monthly method of PHPP – the result is quite similar to the predicted heat energy demand of 50 kWh/(m²a), see Figure 4.6.5. So the measured lower value is only due to the far too low air exchange rate in the apartments with only window ventilation.

Conclusion: Also for modernized buildings, the PHPP calculation is reproduced by the results of measurement if the boundary conditions are represented correctly, including the air exchange rates. With only window ventilation, the air exchange rates are too low to guarantee good air quality. Therefore, all renovated buildings should be provided with controlled mechanical ventilation systems with highly energy efficient heat recovery. This assures for very low heat losses together with a sufficient air exchange rate to provide good indoor air quality.

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5 Supply systems

5.1 Concepts for Net Zero Energy Buildings in refurbishment projects

Florian Kagerer, Sebastian Herkel

5.1.1 Introduction

Regarding the proposed objectives to reduce CO2- emissions significantly it is highly relevant to optimize the energy consumption in the building sector. For that purpose the development of Net Zero Energy Buildings (NZEB) which produces as much energy as they consume within a year is a promising approach. On basis of a highly energy efficient building standard it could be proved for new buildings that net zero energy concepts can be realized with today’s available techniques. From 2019 on the new EU building directive claims Net Zero Energy Buildings as an obligatory standard for new buildings. As the current rate for newly built houses in many European countries is below or about 1% the impact on the CO2 balance will be very low, even if all new buildings are realized as net zero energy buildings. Therefore the energy optimization of the existing building stock is a core target for the future. Zero Energy Concepts have to be adapted to the specific requirements and characteristics of refurbishment projects and have to be developed to an affordable solution to supply new and existing buildings, see [148], [149], [150], [151], [152] and [153].

Motivation

Compared to new buildings one of the main characteristics of refurbishment projects is that due to technical or economical reasons not all known and established measures for energy efficiency can be realized. On this account the energy building standards vary from buildings with nearly no improvements on the building envelope like buildings under historical preservation protection to buildings according to the Passivhaus standard. In any way high efficiency is the basic requirement to get to a Net Zero Energy Building. In this regard especially heat pumps and CHP-units offer the most potential to improve the energy supply of buildings for the time being. Additional both systems offer the possibility of energy management measures by generating or respectively consuming electricity in connection to the electrical grid.

Objectives

Within the IEA Task 37 “Advanced housing renovation by solar and conservation” many best practice examples for multi-family houses as refurbishment projects all over Europe could be shown (See Chapter 8.2). On basis of detailed measurements the energy performance of some selected buildings were analysed (See Chapter 8.1). As a main result it could be stated, that even in renovation the heating energy demand could be lowered to a level of lower than 25 kWh/m²/a.

Taking into account these results of IEA Task 37 the following issues will be discussed in this section:

- Analysis of different kind of building standards as state of the art in refurbishment projects
- evaluation of CHP-units and heat pumps as electricity based supply systems
- estimation of potential for NZE concepts and interaction with the electrical grid

5.1.2 Analyzing of supply concepts based on monitored results

In the framework of IEA Task 37 the building Blaue Heimat (see chapter 8.1 and 8.2.8, building description 513) was monitored in the period July 2009 until Oct. 2010. The monitored Heating energy demand is 19 kWh/m²/year and therefore very low for a retrofitted building. The DHW demand measured 11 kWh/m²/year is in good accordance with the projected value 12.5 kWh/m²a. The measured values justify formidably the efficiency of measures undertaken regarding the building envelope. The energy balance shows high losses for the distribution of the DHW and heating, see (Figure 5.1-3 and Figure 5.1-2). There are different reasons: On the one hand the thermal efficiency of the CHP Unit (56%) is relatively low, on the other hand are due to the floor layout of the building the distribution pipes long (>200m).

Figure 5.1-1
Demonstration building Blaue Heimat, Heidelberg

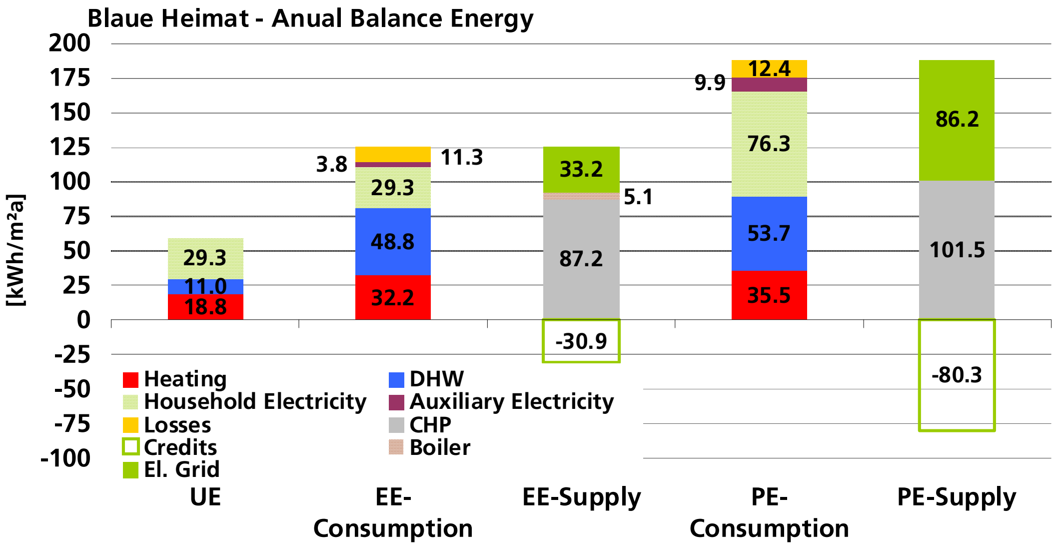


Figure 5.1-2
Measured anual Energy balance (2009/2010).

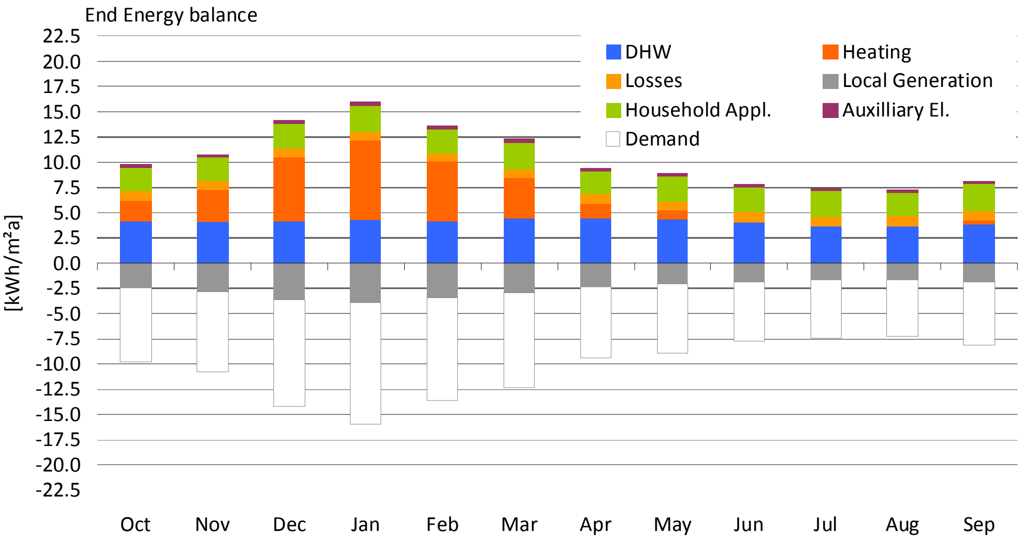


Figure 5.1-3
Measured Monthly end-energy balance (2009/2010)

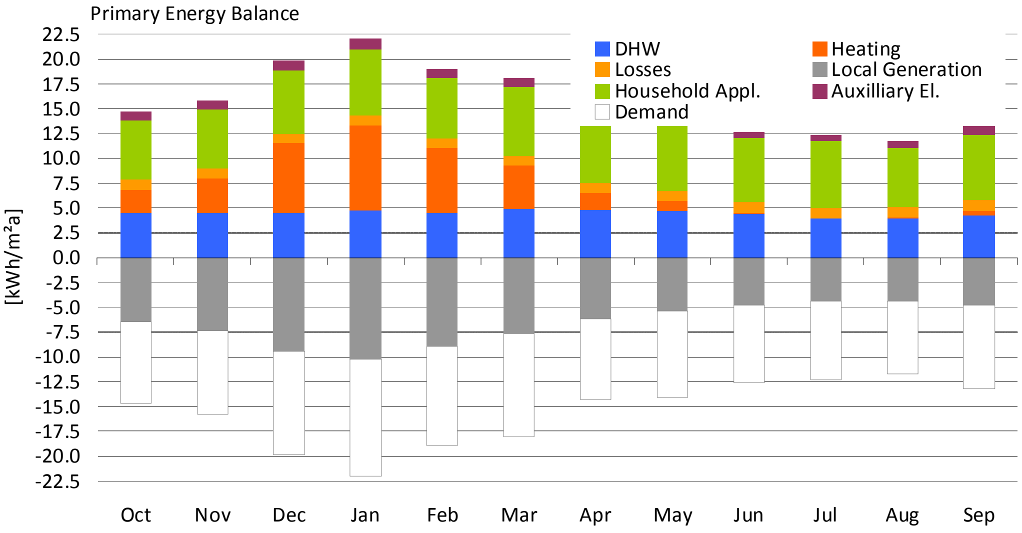


Figure 5.1-4
Montly primary energy balance bases on the measured end-energy balance (2009/2010)

In combination with totally 7 storages the fraction of distribution and storage losses is high. Looking at the DHW it can be seen, that the losses are higher than the demand, the

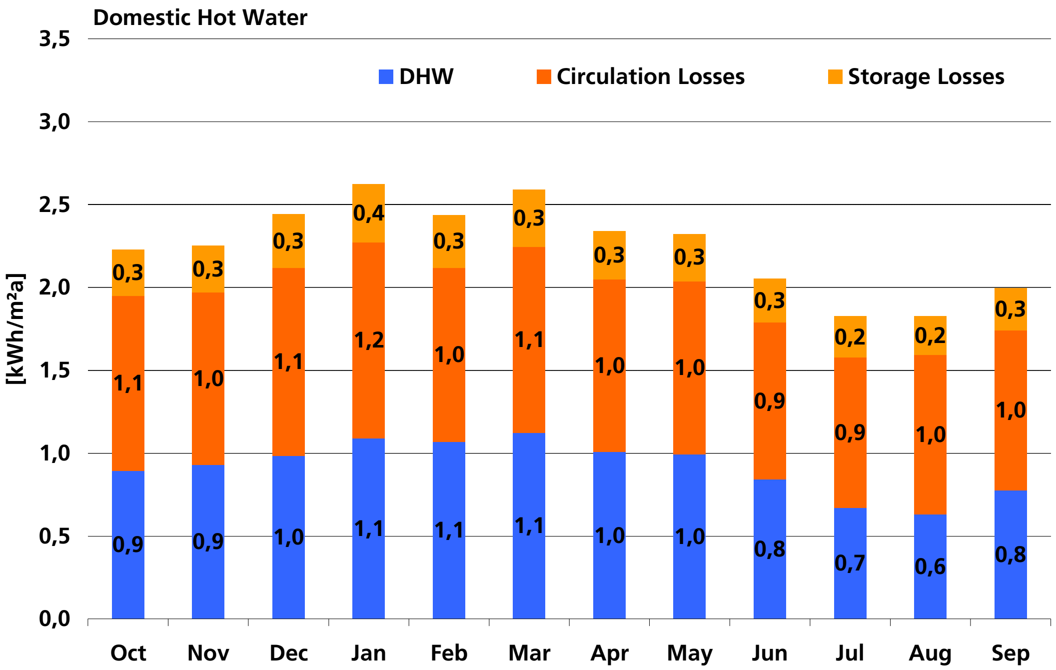


Figure 5.1-5
Measured energy consumption of domestic hot water (2009/2010)

circulation losses (12.5 kWh) are higher than the used heat for DHW (see Figure 5.1-5)

Looking at the primary energy balance, it can be seen, that the building performs very well. Nevertheless the electricity for household appliances is 29 kWhrs/m²/year, which is slightly above the German mean value. Looking at the primary energy balance, an annual demand remains of 107 kWhrs/m²/year primary energy (PE). The primary energy balance shows, that the building fulfils the requirements of the European Commission proposed for new buildings in 2019, to be “Nearly Zero Buildings”. Additional photovoltaic on the roof would allow achieving Net Zero. (See Figure 5.1-4)

Another important issue in future supply system design will be the ability to react on the needs of the electrical grid. The latter will be a key qualification in a changing energy economy towards a higher amount of fluctuating renewables feeding the grid. The ratio between local production and consumption of electricity is an indicator on how the grid is stressed. It could be expressed on different time scales, yearly, monthly daily or quarter hourly as usually used in the electricity markets (see Figure 5.1-6)

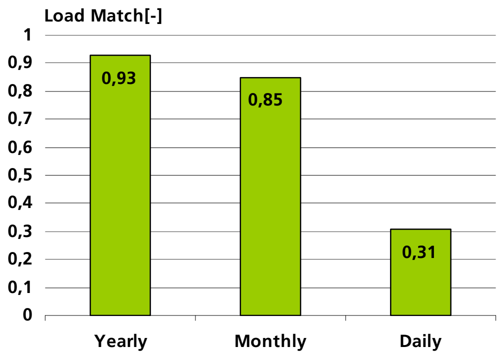


Figure 5.1-6
Measured load match factor of the electricity production and consumption of the Balue Heimat building in Heidelberg, DE

5.1.3 Simulation study I: comparison of supply concepts

In comparison with newly build houses, there is a limitation placed on the attainable energy standards of refurbishments due to their existing construction, building structure or geometry (air tightness, heat bridges), and, in some cases, historical protection requirements. Nevertheless during recent years it was shown in various projects that low-energy standards, up to the passive house standard, are possible even in the field of refurbished construction. Insulating the complete building envelope (roof, façade, basement ceiling) along with the reduction of heat bridges, upgrading windows (triple glazing), and the use of ventilation systems – combined with heat recovery – have been proven to be applicable measures for the existing building stock and can be considered the state-of-the-art.

The present study aims to analyze different supply systems and strategies for heating, domestic hot water, and the control of the system to examine further potential for energy savings. Generation, storage, and distribution are evaluated separately, as well as the interaction within the whole system.

The objective is to compare different supply systems like condensing boiler, heat pumps (exhaust air, outside air, ground source) and CHP- units in combination with and without solar collectors. Secondly it is intended to evaluate different solutions for domestic hot water, storage, and distribution (storage size, system temperature, local heat exchanger for DHW).

Boundary conditions and Introduction of the investigated supply systems

The climate used in the simulation study was for the location of Wurzburg, which represent the average German climate. As a simplification the internal gains and the air change rate are assumed to be constant during the simulation period. The domestic hot water demand is derived from measurement data for the multi family house with 25kWh/m²a. The stochastic load profile is generated and used in the simulation on the basis of the analysis of domestic hot water profiles from IEA Task 28. Starting, the building standard is defined by static calculations with PHPP (Passive house projection packet), and compared with measure data, as well as with simulation data, in order to reproduce the building in the simulation environment as accurately as possible. In the next step, different supply systems are implemented in the building model. The following supply systems are analyzed:

- Air-to-water heat pumps with different heat sources (external air, exhaust air).
- Water-to-water heat pumps with ground-based heat source.
- Condensing boiler.
- CHP unit.

In addition, in two cases exhaust ventilation is used, in four balanced mechanical ventilation with heat recovery is simulated.

The primary energy evaluation takes into account the German primary energy factors of 2.6 for electricity and 1.1 for natural gas.

Results

The results of the simulation study are summarized as follows:

- The heat recovery of the ventilation system contributes highly to the reduction of the energy demand. Preconditioning is an adapted user-behaviour during the heating season. The heat demand is 46 kWh/m²/a without heat recovery and 12 with heat recovery.
- The CHP unit provides the highest efficiency, with respect to the primary energy demand. Comparable results for all other systems are only achieved by combination with solar energy.
- Air-to-water heat pumps with exhaust or external air as heat source are considered on the same level as the reference technology gas condensing boiler at the present mix of primary sources of the electrical grid. The performance of these systems relies highly on the primary energy factor. Without improving the power generation in combination with an increasing use of renewable energies (i.e. best available technology scenario) the performance of a standard condensing boiler achieves a better energy performance than those respective air/water heat pumps with respect to the primary energy factors in

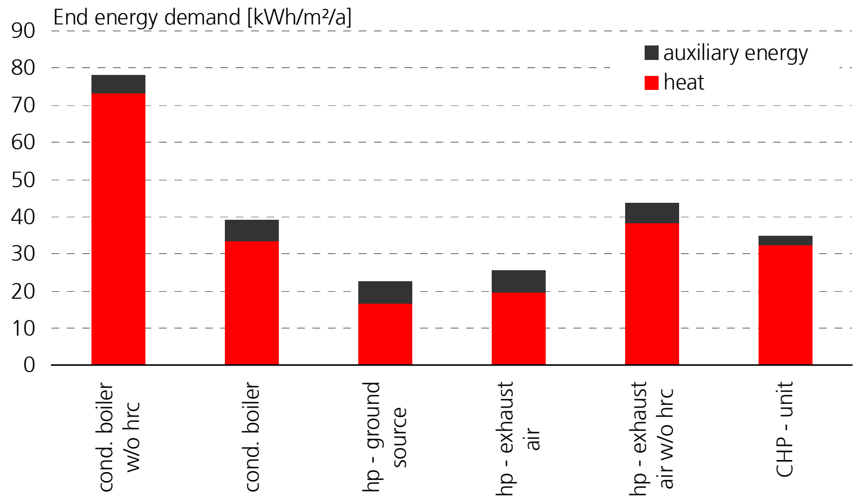


Figure 5.1-7
End energy demand for the multi family housing. The related heated Area is 3375 m²

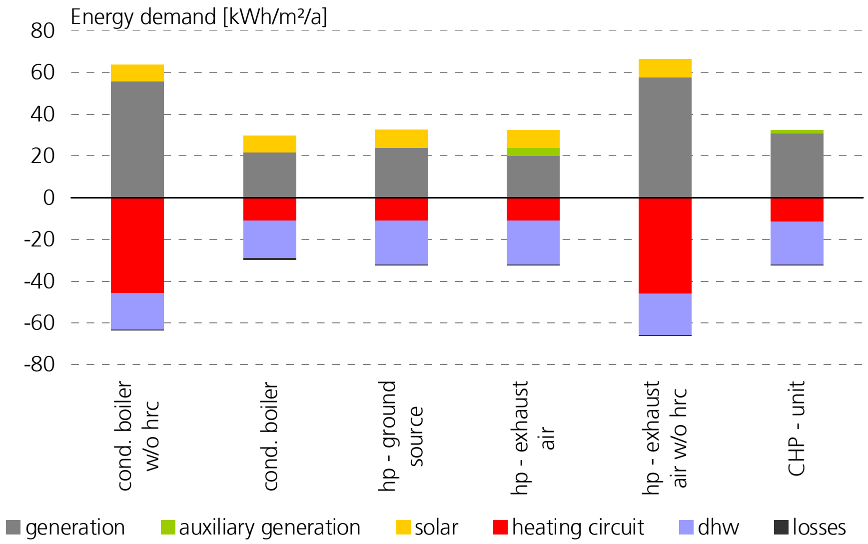
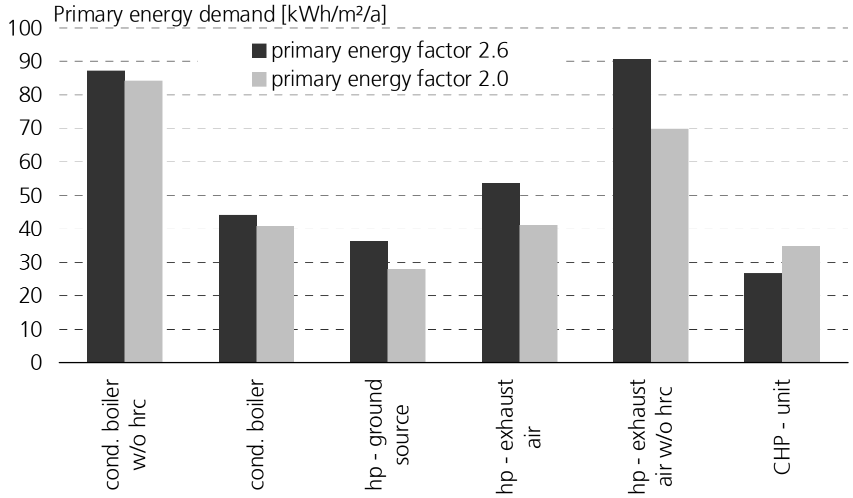


Figure 5.1-8
End energy demand for the multi family housing.



Primary energy demand for the multi family housing. The primary energy factor of 2.0 represents a possible improvement of the power generation network based on the best available technology.

Germany.

- The combination of all generation systems, except the CHP unit, with solar thermal energy reduce the primary energy demand significantly and are therefore considered a basic appliance.
- The implementation of different generation systems (heat pump and solar, condensing boiler and solar, CHP and grid) underlines the relevance of the storage system and adapted control strategies.

5.1.4 Simulation study II Supply concepts for Net Zero in retrofit

The measurement results from building "Rislerstrasse" in Freiburg, DE are used to build up a validated and calibrated basic simulation model for the building and supply system to analyze a Net Zero Energy Building (NZEB) concept [151] Thereon the simulation model is varied according to different building standards and additional supply systems are implemented. All measures for a NZEB are limited to the potential on site. The over all performance of the buildings are analysed and evaluated as well as the interaction between supply system and public grid. The calculations for the energy balances are drawn out for site energy and primary energy. For evaluation two approaches for net zero energy buildings are considered:

Figure 5.1-9
Demonstration building Rislerstrasse Freiburg, used as base case for simulation study:
~ 40/60 kWh/m²a primary energy demand
Condensing boiler with solar thermal collectors.

- Total energy demand including energy for heating, domestic hot water, auxiliary energy and all household appliances.

- Supply energy demand, including energy for heating, domestic hot water and auxiliary energy.

The primary energy evaluation takes into account the German primary energy factors of 2.6 for electricity and 1.1 for natural gas.

Building description and boundary conditions for simulation

The simulated building is a 3 storey multi family house with 18 dwelling units (Rislerstrasse, Freiburg). The net heated floor area sums up to 1550 m² and the ratio of the building envelope to the heated volume is 0.46. The building is orientated to the south/ south-west and provides good conditions for solar appliances like photovoltaic and solar thermal; see Figure 5.1-9 and Figure 5.1-10.

The energy building standards of the different analysed building (see Chapter 8.1) varies with different qualities of the building envelope. In all cases a mechanical ventilation system is implemented in combination with and without heat recovery. The air change rate is considered for infiltration, mechanical ventilation and user behaviour. Internal loads are taken into account with 2.1 W/m².

Out of a variety of supply systems the focus in this second analysis is made on heat pumps and CHP-units. Both systems offer the possibility to increase the energy efficiency of the heating supply for the building and additionally to contribute to a load management strategy by interaction with the electrical grid. The latter will be a key qualification in a changing energy economy towards a higher amount of fluctuating renewables feeding the grid.

The systems are combined with a 3500 litre buffers storage and 50 m² solar thermal collectors for domestic hot water and heating. For generating electricity photovoltaic is applied on the available roof area of 250 m².

In Figure 5.1-11 the simulated energy demand for different building standards are shown. The heat load sinks drastically with an

Figure 5.1-10
Ground floor and facades of simulated building.

Table 5.1-1
Different alternatives for building standards.

ACH-Rates	ACH-mechanical	ACH-user	ACH-inf	Total U-value
e^{-}	-	0.60	0.10	0.7
$e^{\sim}$	0.50	0.20	0.10	0.42
e^{+}	0.50 – HRC 85%	0.30	0.10	0.30
e^{++}	0.30 – HRC 85%	0.20	0.10	0.30

Table 5.1-2
Supply systems for heating and electricity.

Supply system	PV	Solar thermal	tank
HP 25kWel	250m²	50m²	3,5m³
CHP 50kWth 35kWel	250m²	50m²	3.5m²

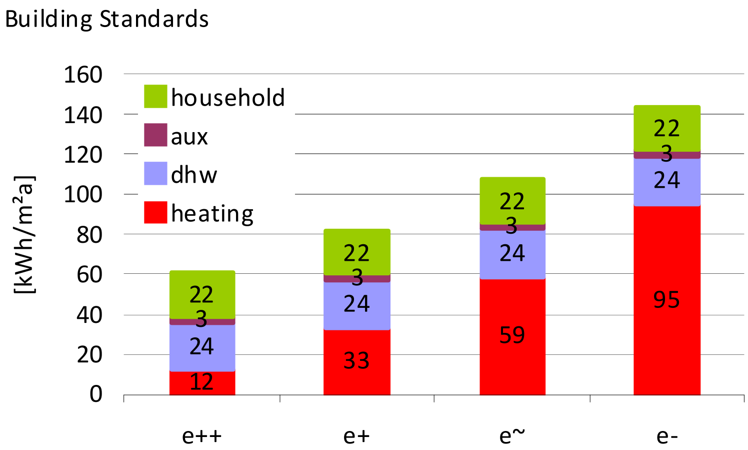


Figure 5.1-11
Energy demand for heating and domestic hot water for different building standards.

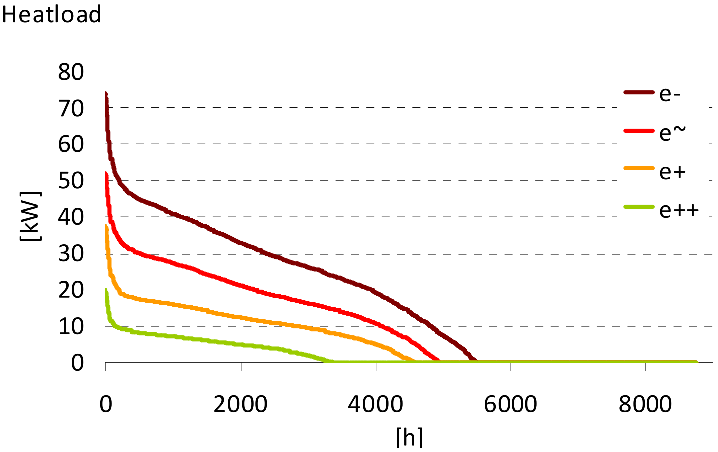


Figure 5.1-12
Heat load of different building standards

increasing building standard, see Figure 5.1-12.

Annual Primary Energy balance

The annual balance for the systems heat pump + solar thermal, CHP and CHP + solar thermal are shown in Figure 5.1-14, Figure 5.1-15 and Figure 5.1-16 (right side, rectangular symbols). The simulation results show that a balanced energy consumption and production considering the total energy demand including household appliances is not possible with the analysed systems. In comparison to single family houses the available areas for solar thermal or photovoltaic is limited, especially if related to the net heated floor area. The CHP-unit enables with all buildings standards an energy balance close to net zero just for the supply system (see Figure 5.1-15, triangle symbols).

Beside the photovoltaic the benefits for the electricity production by the CHP unit are essential. The heat pump supply system does not reach a zero energy balance for both standards and for both approaches (total energy / supply energy demand). The main requirements for zero energy buildings are to further improve the over all efficiency of the supply systems and to increase the fraction of renewable energy for heat generation on site. Whereas for single family houses net zero energy concepts are already available in different alternatives, for multi family houses the most promising concept is limited to a supply system based on CHP units at the moment. Only a combination with the use of biomass enables a net zero energy balance for all energy appliances on site.

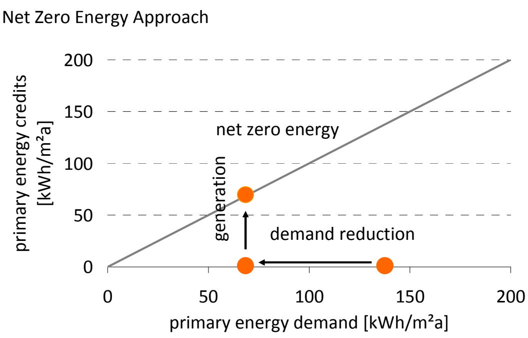


Figure 5.1-13
Net Zero Energy Approach: A building is called a NZEB, when the local production of primary energy is higher than the consumption at site on an annual base.

Grid match of locally produced electricity

In future the ability of the local electricity generation to match the local demand not only on an annual base but as well on shorter time periods is a prerequisite for further

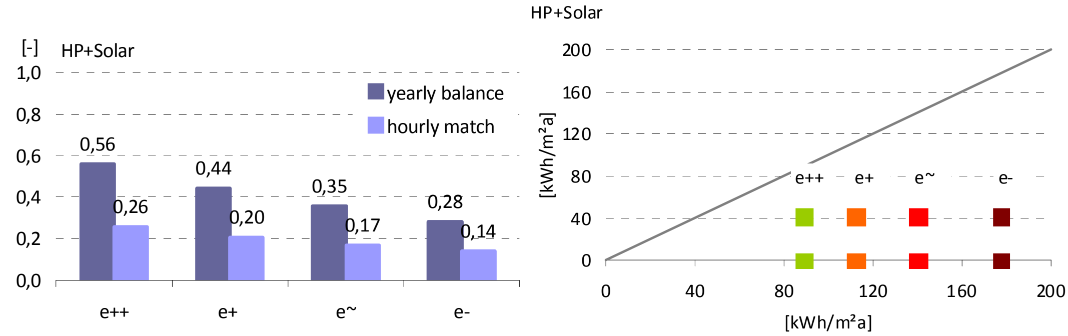


Figure 5.1-14

Anual Primary Energy Demand and on-site generation for a heat supply system combining heat pumps and solar thermal for different building standards (right side).

Grid Match factor (yearly and hourly) for the same buisupply system and building standards

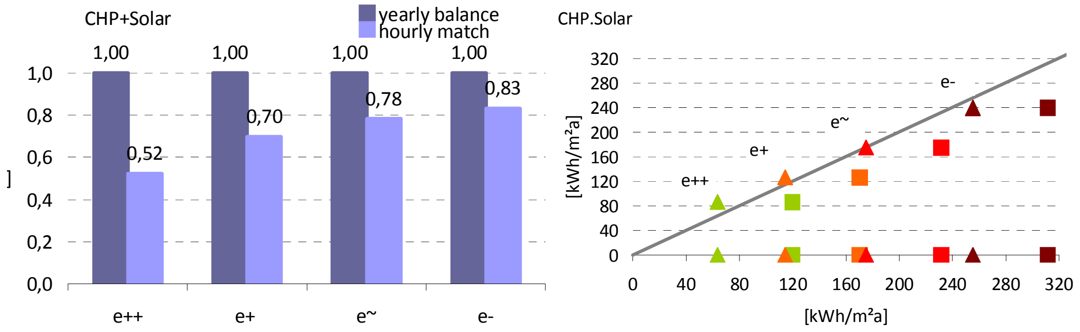


Figure 5.1-15

Anual Primary Energy Demand and on-site generation for a heat supply system combining CHP and solar thermal for different building standards (right side).

Grid Match factor (yearly and hourly) for the same buisupply system and building standards

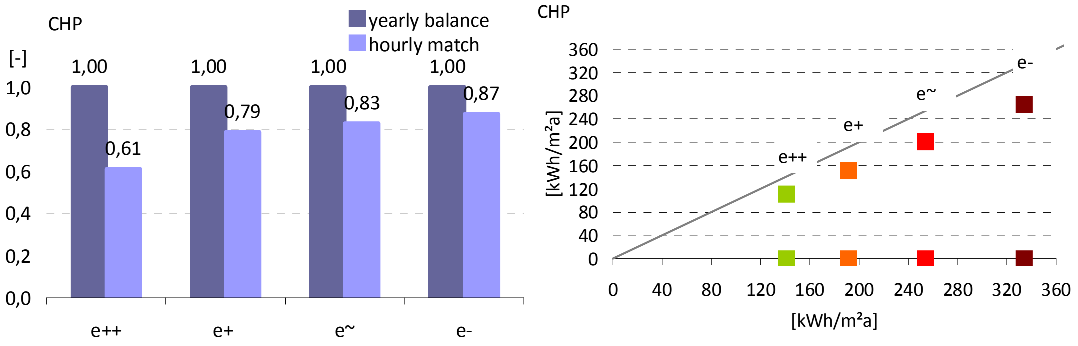


Figure 5.1-16

Anual Primary Energy Demand and on-site generation for a heat supply systembased on a CHP for different building standards (right side).

Grid Match factor (yearly and hourly) for the same buisupply system and building standards

increasing renewables in the electrical grid. The grid match factor of the three simulated supply concepts are shown in Figure 5.1-14, Figure 5.1-15 and Figure 5.1-16 (left side). Due to the more continuously operation of the CHP the grid match factor for these systems are up to 80% even on a hourly base.

Conclusion

The simulation study shows that Net Zero Energy Concepts for multi-family houses are still a challenge. Depending on the definition of Net Zero Energy Buildings especially the total energy approach with a consideration of the household electricity demand is difficult to realize on site. Following the main results and topics are summarized

- Energy efficiency of existing building stock can be improved significantly with known and established measures.
- Due to limited roof and façade areas for photovoltaic the NZEB approach for multi family houses considering the total energy demand can be realized for the presented buildings only with heat supply systems which are based on renewable energy.
- The most promising approach for supply systems are CHP-units. A combination with solar thermal is possible and mainly a matter of economics.
- A Net Zero Energy concept totally based on electricity (combination of heat pump and photovoltaic) can not yet be realized for the total energy as well as for the supply energy approach
- Further analysis of potential for interaction between building and electricity grid or district heating has to be done in order to reduce grid mismatch and grid stress.
- With better building performance the influence of household electricity increases

significantly. Therefore measures on electrical efficiency have a higher impact on the total energy balance.

5.1.5 References

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5.2 Mechanical systems, integrated "standard" system supplying air, heating and DHW

Anil Parekh

The purpose of this Builders' Manual is to provide information that builders can use to build better houses – houses that require less heating, cooling and domestic hot water compared to a conventional home. The use of integrated mechanical units is one more step that builders can take to optimize energy efficiency. Problems that persisted with field-assembled "combo" units have been addressed as a result of research and the implementation of a CSA standard for modern integrated mechanical units.

Introduction

For the most part, conventional heating and cooling systems are simply not available in small enough sizes for houses that are very energy efficient. Consider the following:

- Improvements to the building envelope have reduced space heating loads to the point where, in energy efficient homes, purchasers may question that the expense of a high efficiency furnace based only on the space heating savings.
- Certified oil-fired furnaces are not commonly available in Canada with fuel inputs under about ½ USGPM (20.5 kW; 70,000 Btu/h). As a result, it is difficult to obtain a close match of oil fired space heating equipment and the low design heating loads of energy efficient homes.
- Domestic hot water (DHW) consumption and loads have remained fairly constant over time, while space heating loads have been significantly reduced in newer homes. Water heating loads may be high, but are intermittent. However, the water heater system must have sufficient storage (or capacity) to satisfy peak demands. As a result, the average daily water heating load factor is low, and it is almost independent of the outdoor weather conditions. This means most homes will have an under-utilized water heating capacity.
- Ventilation is required when the home is occupied and this results in the need for an air handler to be running most of the time.

Combining the space and water heating functions with an integrated system can help to resolve these issues. Combining space heating and ventilation can reduce the number of fans needed and thus the energy to run them. Using a system that has hot water storage decouples the space heating loads from the burner and allows the burner to operate longer but less often during periods with low loads. Reduced cycling of the burner can improve efficiencies and reduce wear on the components. These realities lead to the concept of integrating mechanical functions to increase efficiencies. This led to the development of field-assembled integrated mechanical systems (combos) that combined heating, ventilating and domestic hot water. From a builder's perspective, there are a number of reasons integration of mechanical functions makes sound business and design sense. Combining the operation of mechanical equipment can:

- Simplify the installation and commissioning of the HVAC package.
- Decrease the number of interconnections and penetrations that need to be made in the exterior building structure for air supply, exhaust and fuel supply.
- Decrease the capital cost of HVAC equipment through a reduction in ductwork, number of motors, blowers, burners, casings, and cabinets.
- Some utilities include approved combo water heaters in their rental programs, and some offer direct incentives to builders to install these systems, either as stand-alone water heaters or as combined space and water heaters.
- Benefit the home buyer through reduced operating costs for electrical energy and fuel.
- Provide improved comfort and increased usable floor space for small-footprint integrated systems.

It is important to know where the industry has come from in order to understand where it is going so the following sections are provided for clarity.

The Evolution of Integrated Mechanical Units

The integration of mechanical functions was initially done on an experimental basis and is now supported by research and standards, to improve performance, reliability and energy conservation.

Field assembled (combo) systems

The combining space and water heating systems (combos) was first introduced in Canada in the 1980s. The idea was to use a water heater as the energy source for space heating and thereby reduce the "first cost" of residential heating systems and increase the utilization factor of the water heater. Unfortunately there were problems with the early combo systems - some simply did not provide enough heat. When water-heater based combos were first introduced it was believed that it would improve the overall efficiency of the water heaters. The theory was that the Energy Factor water heater performance rating already accounted for standby losses from the water heater and therefore that any incremental loads that were applied on the water heater in a combo application would be supplied at a marginal efficiency at least equivalent to the recovery efficiency of the water heater. Field experience demonstrated that this was not the case. The recovery efficiency (and energy factor) of a residential water heater is determined with cold water entering the system at 14.4°C (58°F). In a combo application, water is returned to the heater at a higher temperature of at least 55°C (130°F) or higher. As a result, there is little correlation between the recovery efficiency of a water heater and its efficiency when providing space heating. The same was found to be true when a boiler is used in a combo application. A boiler is rated by its Annual Fuel Utilization Efficiency (AFUE). AFUE is determined from stack-loss combustion measurements obtained while it is operating in a "steady-state" condition with return water at 120°F and supply water at 140°F. A number of minor adjustments are made to the steady state efficiency measurement to obtain the AFUE rating. In a combo application, the operating conditions may be substantially different, and part-load losses may be much greater than what is used in the AFUE calculation. Because of the wide range of technologies and components being used in residential combos, as well as the performance differences that can result from different approaches to controls, system design and system-sizing, developing reliable estimates of the operating efficiencies of combos from component performance ratings is not considered feasible. In most cases, the space heating efficiency of a water-heater based combo will be less than the recovery efficiency or thermal efficiency of the water heater. Space heating efficiency is likely to be substantially lower than recovery efficiency in air-handler systems that have high return water temperatures. To address these issues, hydronic and combo guidelines were first developed in 1987 in British Columbia to respond to the many complaints from the public regarding the inability of the combo heating systems to provide adequate heat. In 1997, HRAI published the first edition of a Unified Canadian Guideline (UCG) for Integrated Combo Systems. The UCG is a design, selection and installation guide that includes recommendations on:

- How the design heat loss should be determined,
- How combo systems should be sized,
- Design rating conditions for combo air-handlers, and
- How a water heater and an air-handler should be matched.

In spite of these efforts to improve the success rate of combos, problems persisted.

Research

Recognizing the potential benefits of integrating mechanical functions properly and the need to improve the poor record of filed-assembled combos, Natural Resources Canada and manufacturers of heating and cooling equipment launched the EKOCOMFORT® project to develop integrated products to consolidate loads and reduce the payback time on more efficient components. Natural Resources Canada established an Advanced Integrated Mechanical Systems (AIMS) program in the 1990s to encourage the development and deployment of efficient, integrated systems that recognized that heat recovery ventilation has become one of the core functions needed for residential HVAC in modern, energy efficient homes.

Following extensive consultations with HVAC manufacturers, the Heating Refrigeration and Air Conditioning Institute (HRAI) and natural gas utilities, NRCan published AIMS performance targets and challenged manufacturers to develop integrated products that exceeded those targets. Although integrated products were not included in any efficiency regulations, the minimum performance levels for each of the space heating, water heating, and heat recovery ventilation functions were set at higher levels than the then-existing requirements for regulated, single-function products. Minimums were developed for system capacities for each HVAC function and maximum electrical energy consumption targets were included to cut electrical use by half compared with an equivalent group of conventional products that would typically provide the same functions. The

EKOCOMFORT® trademark was developed as a mechanism to identify products that complied with the performance requirements.

The selected manufacturing teams used a broad range of technologies and design approaches in the systems that were deployed. All of the integrated systems used water-to-air coils to provide space heating, and all used brushless permanent magnet motor with their main air-handlers. Domestic water storage capacities ranged from none to over 70 gallons. Two systems used modulating burners, while three used burners with fixed capacities. All were gas-fired, but three systems also provided an option for operation with fuel oil. Heat recovery ventilation and distribution of fresh air was integrated into each product. The industry demonstrated that the goals could be achieved and it became evident that standardization was required if these technologies were to become common place in the housing industry.

Standard development

Based on the pioneering work done by AIMS and EKOCOMFORT, CSA Standard P.10-07 Performance of Integrated Mechanical Systems for Residential Heating and Ventilation was published in 2007. The Standard is based on performance rather than on the types of components used. This means the standard should be able to incorporate new technologies as they develop. CSA P.10-07 includes performance testing and factory adjustment of the water heater, space heating, ventilation functions and controls and testing of the combined unit. The evolution from field-assembled combos to integrated mechanical units whose design and performance is governed by a standard means that builders the energy efficiency potential of combining functions can be realized and the risk of problems is greatly reduced.

Code-compliant integrated mechanical units

The first integrated mechanical unit tested and certified to CSA P.10-07 was introduced in 2007 (Figure 5-1). The unit integrates a modulating, fast response, low-mass condensing "boiler", a water to air heat exchanger with a variable speed brushless permanent magnet motor, a segregated hot water heater using a brazed plate heat exchanger, and a heat recovery ventilator. It uses advanced controls to continuously monitor performance, and automatically adjust its firing rate, blower circulation speed, and load priority. It is expected that other CSA P.10-compliant integrated mechanical units will be available soon. Experience has demonstrated that trying to piece together equipment on-site to "integrate" systems has been problematic. Builders are encouraged to specify and use equipment certified to the CSA P.10-07 Standard.

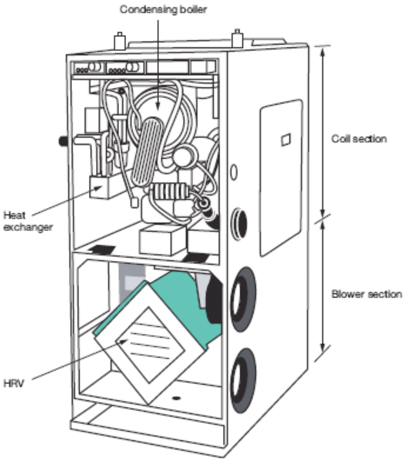

Figure 5.2-1
Sample CSA P.10-compliant integrated mechanical system unit

Control systems for integrated mechanical units

Integrated mechanical units require that the control strategy and operation be planned carefully to ensure the system operates at peak efficiency. By selecting IMS that have been certified to the CSA P.10-07 Standard, the user is assured that the control system as designed and provided will perform in the manner to which it was intended. IMS appliances are often provided with sensors not typically included with standard warm air furnaces. These may include an outdoor air temperature sensor, supply air plenum temperature sensor, circulation air proving switches, or other devices. These are often vital to the correct operation of the appliance, and must be installed in accordance with the manufacturer's instructions.

Controlling hydronic zones

Integrated mechanical units offer both forced air heating and hydronic heating. For this reason, integrated mechanical units are often selected for applications requiring both forced air heating and some amount of hydronic heating (such as zone in-floor radiant heat, hydronic baseboard radiators, pool heating, etc.). In these situations, hydronic zone control is necessary.

Each hydronic zone will require a thermostat (or temperature sensor), and either a zone valve or zone circulator. The preferred approach to controlling multiple hydronic zones is to add a zone controller. Zone controllers are available from several manufacturers that simplify the field wiring of multiple zones and the interconnections to the IMS appliances field connection terminal strip. In terms of a control strategy, IMS appliances usually provide priority to calls for domestic hot water over calls for space heating. This is because heating and heat loss is a slow process with long "on" duty cycle times, whereas domestic hot water usage (showers, dishwashing, hand-washing) require a fast response and are characterized by comparatively short duty cycles. In some cases a call for forced air heat is given priority over a call for hydronic heat. This requires that heat delivery to hydronic zones be halted briefly at certain times. The IMS manufacturer's literature should be carefully consulted by the installer to ensure that the appropriate connections are provided so that the internal controls of the IMS appliance are capable of shutting zone circulators or valves when required.

Tempering (anti-scald) valves

Building codes usually require tempering or anti-scald valves. Packaged IMS appliances may or may not be shipped with an anti-scald device included or it may be supplied loose. The IMS installer must ensure that an anti-scald device is installed, adjusted, and working correctly.

HRV and humidity controllers and de-humidistats

IMS appliances contain a heat recovery ventilator (HRV). Most IMS appliances will feature a set of contacts on the field connections terminal strip to which HRV controllers or de-humidistats can be wired to allow the homeowner to force high ventilation capacity. The installer should carefully review the contacts available to ensure compatibility with the desired HRV controller, if one is being planned in addition to the controls provided with the IMS. There are several types of HRV controllers. Some offer manual commands in addition to automatic control. Automatic HRV controls are available that detect indoor humidity (de-humidistat type control), others are capable of detecting a blanket of indoor pollutants. It is also possible to utilize a carbon dioxide sensor as part of a ventilation control strategy. While the carbon dioxide sensor provides a good indicator for ventilation needs (CO2 is a by-product of respiration which indicates people are present) these sensors can expensive and may require annual calibration. Several manufacturers offer controllers that allow occupants to program a seven day schedule of daily ventilation events that coincide with their occupancy of the residence. If a humidifier is to be provided, then the controller and humidifier will operate independently of the IMS, but should be at least wired so the humidifier controller is powered from the IMS low voltage power source provided for thermostats. Preferably, an interlock should be provided so that the humidifier can only operate when there is a demand for humidity and the main circulation power is operating.

Optimizing Thermal Zones

As with any condensing appliance, be it a high efficiency hydronic boiler or a Premium efficiency IMS, the actual (installed) efficiency is dependent on its ability to condense. If hydronic zones are being considered (such as zone in-floor radiant heat, hydronic baseboard radiators, pool heating, etc.) there may be an opportunity to help the appliance condense. When the final return water temperature to the appliance is below approximately 48 °C, then a condensing appliance will be able to condense. Therefore it is best to arrange the thermal zones in such a fashion as to achieve the lowest possible return temperature. For example, if one zone will be serving a portion of radiant floor heating (a low temperature load), and another zone will be serving some convectors or radiators (high temperature loads) then the designer should carefully consider the arrangement of the heating circuits to produce the lowest possible return water temperature.

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5.3 Household Appliances: Significant primary energy reduction concepts

Frans Koene

Abstract

In the RIGOUREUS project, ECN, TNO, TU Delft end DHV cooperate to develop advanced and affordable renovation concepts for terrace dwellings in The Netherlands, aiming at reducing the total (primary) energy consumption by 75%. The basis is the Passive House concept to which a number of additional measures are added, including 1) reduction of domestic electricity by using standby killers and A-label appliances, 2) installation of a large (8 m2) of evacuated tube solar collector to supply heat for space heating, DHW and hot fill of dishwasher and washing machine and 3) replacing the boiler with a high efficiency heat pump. The more of these measures are included, the fewer PV cells need to be installed to reach the target.

5.3.1 Introduction

The energy consumption in the built environment accounts for approximately one third of the total energy consumption in The Netherlands. The introduction of the Energy Performance Coefficient EPC in The Netherlands in 1998 as a mandatory requirement for new buildings has contributed considerably to the reduction of the energy consumption of new dwellings. However, so far little effort is undertaken to reduce the energy consumption of existing buildings.

In the RIGOUREUS project, ECN, TNO, TU Delft and DHV develop advanced renovation concepts aiming at a reduction of 75% of the total (primary) energy consumption for Dutch terrace dwellings. Key aspect in the realisation of this target is minimisation of heat losses and maximisation of the solar contribution, while reducing the building related and user related electricity consumption. The basis for these concepts is the Passive House concept [158], minimising the energy demand for space heating, in combination with a solar collector to reduce the energy demand for DHW. Even though these concepts are well known in German speaking countries, several factors have prevented widespread application in the Netherlands, such as: fear of the unfamiliar, the typical Dutch building practice and economical considerations. Nevertheless, it is regarded as a necessary starting point for energetically ambitious renovation concepts.

5.3.2 Energy consumption of a Dutch terrace dwelling

An analysis of the building stock shows that the category 'terrace dwellings' built between 1945 and 1975 makes up a major part of the total building stock, both with respect to number of dwellings and energy consumption. In the next decade, these dwellings will be in need of renovation. For these reasons, this type of dwelling, shown in Figure 5.3-1, is selected as the object for the renovation concepts.

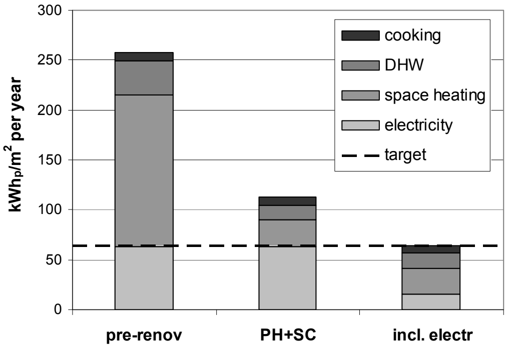

Figure 5.3-1
Post war Dutch terrace dwelling and breakdown of primary energy demand.

The annual energy consumption of such a dwelling consists of approx. 2.000 m3 of natural gas (for space heating, DHW and cooking) and approx. 3350 kWh of electricity. It is assumed that there is no need for cooling in these dwellings in their current state nor will there be after renovation. In terms of primary energy (denoted with the index p), the total energy consumption adds up to 260 kWhp/m2a, shown by the left bar in Figure 5.3-1. The target of the RIGOUREUS project is to reduce this figure by 75%, down to 65 kWhp/m2a. The ambition of the RIGOUREUS project therefore is almost twice as high as the Passive House quality mark (120 kWhp/m2a).

Appliance group	electricity consumption [kWh_e/a]	saved in step 1 [kWh_e/a]	remaining after step 1 [kWh_e/a]	saved in step 2 [kWh_e/a]	remaining after step 2 [kWh_e/a]
oven, microwave etc.	96	*27*	69		69
cooking utensils	136	*22*	114	*66*	48
hobby	8	*2*	6		6
personal care	16	*4*	12		12
audio/ video/ communication	629	*189*	440	*51*	389
heating / DHW	271	*50*	221		221
fans etc.	26	*0*	26		26
Refrigerator, freezer	589	*6*	583	*359*	224
Cleaning	1213	*0*	1213	*174*	1039
lights (mainly incandescent lamps)	642	*90*	552	*366*	186
Other	46	*10*	36		36
Total	**3672**	***400***	**3272**	***1016***	**2256**

Table 5.3-1
Appliances and their electricity consumption in a Dutch household after two steps to save energy.

The middle bar in Figure 5.3-1 shows the energy demand of the terrace dwelling after the energy demand for space heating has been reduced to 25 kWh/m2a by the application of the Passive House concept and the energy demand for DHW has been reduced by 50% by the use of a (small) solar collector. As Figure 5.3-1 shows, these measures do not suffice to reach the target. The remaining energy consumption is now dominated by the domestic electricity consumption. This too should be reduced in order to reach the target of 65 kWhp/m2a, as shown by the right bar in Figure 5.3-1. In fact, the issue of reducing the domestic electricity consumption is all the more important because in The Netherlands, as in the EU, electricity consumption shows an increase of approx. 2% per year between 1990 and 2006 [159].

5.3.3 Measures to reach the target of 75% energy reduction

Starting from the middle bar in Figure 5.3-1, the question is how to further reduce the primary energy consumption of a dwelling, in particular the (net) electricity consumption. Following the Kyoto pyramid, the three steps to reduce energy consumption are (in this order): 1) reducing energy demand, 2) application of renewable energy and 3) efficient use of fossil energy. The potential of each step is explored in the next sections.

Reduction of domestic electricity

On the basis of the Basic Survey Electricity Consumption of Small Users [160] a list is composed of electrical appliances in a typical Dutch household. In this survey the degree of penetration, being the percentage of households that owns a particular appliance is also listed. In the present list, common appliances (penetration > 50%) are assumed to be present, while less common appliances (penetration < 50%) are left off the list. The resulting list is shown in Table 5.3-1.

The electricity consumption of the remaining appliances adds up to 3670 kWhe/a, which is a bit higher than the average figure in a Dutch dwelling (3350 kWhe/a). A number of steps are discussed below to reduce this electricity consumption.

Step1: Elimination of standby electricity

In an average household, electricity consumption of standby modus makes up approx. 10% of the total consumption, which can be significantly reduced by application of so called ‘stand-by killers’. Different types of stand-by killers are available on the market. However, a more structural approach on the level of building related measures would include the implementation of a series of wall outlets of a different colour (e.g. green) that can be switched off during the night or in absence of the occupants. By eliminating all standby electricity the annual electricity consumption of the appliances on our list can be reduced by approx. 400 kWh/a (11%). This is a rather optimistic figure to achieve in practice as not all appliances are suited for standby killers (in particular those with a clock or a timer). Also some appliances’ standby consumption can only be reduced during the night.

Step 2: Replacement of appliances by the most energy efficient variant (A-label)

This step shows the potential of reducing electricity consumption with the state of the art technology. Table 5.3-1 shows that the largest gains in terms of kWhe/a are achieved by application of low-energy light bulbs and replacing the refrigerator and the freezer with an A-label combined refrigerator-freezer. With these and a number of other small replacements, the average Dutch tenant can save another 1016 kWhe/a (28%).

Step 3: Low energy or renewable energy appliances

When considering the appliances remaining after step 2, a number of these require heat that is supplied in the form of electricity, such as the dishwasher or the washing machine. Offering heat from a boiler, a Combined Heat and Power plant (CHP) means that we avoid the heat losses in the electricity plant (50%) where the electricity is being generated. An even more desirable option is to use solar heat from a solar collector. This option is further discussed in section 3.2.2.

Another major consumer of electricity in dwellings is the tumble dryer. Gas fired dryers are a good alternative or, more ambitiously, a drying room fed with waste heat from e.g. the refrigerator. Further reductions are possible. Research is being carried out on dishwashers that require no more than a single cup of water. Using the right soaps/enzymes, washing could be carried out at much lower temperatures, saving on the need for water heating. Drying at low temperatures, using a fan rather than a heater also lowers the heating demand.

Refrigeration is also a major electricity consumer. This can be done more efficiently using a cool room or cool cupboard in the house, which is efficiently cooled with ground heat exchangers or by cold from the evaporator side of the heat pump. Implementation of a top lid on the refrigerator avoids losses when opening the door. A carousel system can provide easy access to all wares stored. A bonus for all these savings is a reduction in internal gains, which will reduce the risk of overheating of the dwelling during the summer. However, it is doubtful whether we can achieve a factor of 4 in the reduction of domestic electricity consumption with the three steps described above. That means that in order to reach our target of 65 kWhp/m²/a, additional measures are needed. This is the next step in the Kyoto Pyramid.

Application of renewables

Renewables can be introduced by locally installing Photovoltaic (PV) cells or solar collectors or by importing ‘green electricity’ e.g. from an offshore wind park. The latter however is unacceptable in this project. We chose to limit ourselves to renewable energy installations for which the investment comes from the renovation budget.

Application of Photo Voltaic (PV) cells

One option to reach the target is the application of PV cells. Starting again from the middle bar in Figure 5.3-1, the target can be reached by installing 30-35 m2 of PV-modules of optimum orientation on the roof. However, for technical or architectural reasons this may not always be possible or feasible in renovation. In addition, it may not be very economical, which for Dutch builders is an important criterion. The amount of PV, required to reach our target is therefore used as a measure of the success of other measures. This will be discussed in section 4 below.

Large solar collector system

As mentioned before, main consumers of electricity in a typical Dutch household are appliances such as a washing machine and a dishwasher, which can also be fed with (solar) heat (hot fill). The Dutch practice is to apply (if at all) a rather small solar collector, usually in the order of 3 m2 and a storage vessel of typically 150 l. These are rather modest sizes compared to the practice in e.g. German speaking countries, where collector areas are found of up to 15 m2 and storage vessels of up to 2 m3 [161].

Simulations were carried out to see how much a larger solar collector system can contribute to the target of reducing the energy consumption by 75%. The scope of the simulations carried out is broader than just saving on electricity consumption; it includes savings on energy demand for space heating, DHW and hot fill.

The area of the evacuated tube collector is varied between 3 and 23 m2, and for each, the volume of the storage vessel is varied between 0.15 and 10 m3. Although the latter value is perhaps a little high for a single family house, the simulations were carried out to show the potential of the system. The results are compared to those of the base case, a 3 m2 vacuum collector with a 150 l storage vessel which is used solely for DHW production. The savings on primary energy are shown in Figure 5.3-2.

The solar contribution to the total primary energy savings for space heating is calculated assuming that in the absence of a solar collector, the heat has to be generated by a boiler with an efficiency of 95% (on lower heating value). Similarly, for DHW the efficiency of the boiler is assumed to be 75%. For hot fill the savings are calculated assuming that in the absence of the solar collector, electricity has to be generated in a power plant with a primary energy efficiency of 50%. When the solar collector cannot supply enough heat for the hot fill, there is still a gain in primary energy because the heat is then generated by the boiler with efficiency of 75% rather than in the electricity plant with 50% efficiency.

From figure 3 it appears that even with rather modest collector sizes in the order of 8 m2, there is a substantial saving of 15-20 kWhp/m2a over the base case. This corresponds to a solar fraction of about 45% of the total heating demand for space heating, DHW and hot fill. It also appears that at this collector area, the size of the vessel is not so important, provided it is at least 0.6 m3. Finally, simulations without heat losses of the vessel show that in the system modelled, heat losses have limited effect on the solar fraction with vessels of 3 m3 or less.

Efficient use of fossil energy

This is the third step in the Kyoto pyramid. Two promising technologies are the Combined Heat and Power plant (CHP) and the high performance heat pump. In The Netherlands, several small (micro) CHP plants are available for application in dwellings. In analogy to high efficiency boilers, a so called HRE quality mark is being introduced for units with a Primary Energy Ration (PER) of 140% or more.

Alternatively, state of the art heat pumps achieve a Seasonal Performance Factor (SPF) of 2.5-3 for DHW and 4-5 for space heating. Assuming an electrical efficiency of 50% in the electricity plant, this translates to a PER of 140% for DHW and 220% for space heating. Application of such a unit with a thermal output in the 2-5 kWth-range would save an additional 15-20 kWhp/m2a in our terrace dwellings.

5.3.4 Summary

Table 5.3-2 summarizes the effect of the different scenarios. The first scenario is the base case consisting of the Passive House concept plus a 3 m2 evacuated tube solar collector and a 150 l storage vessel. Additionally, in case 2, domestic electricity is reduced by 39% using standby killers and A-label appliances. Here, innovative measures such as low energy coolers are not included.

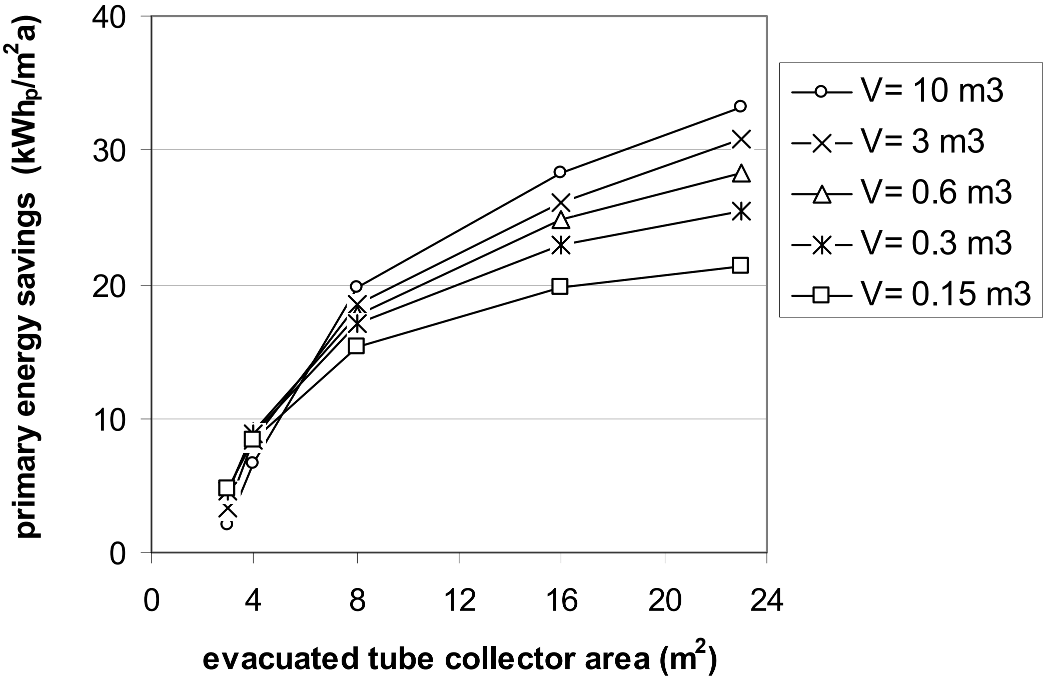

Figure 5.3-2
Savings on primary energy with a solar collector for space heating, DHW and hot fill as a function of collector area, compared to base case.

Scenario	Description of measures	Primary energy demand [kWh_p/m^2a]	PV to reach target [m^2]
1	Passive House + 3 m^2 solar collector+150 l storage vessel for DHW	113	32
2	As scenario 1 plus step1+2 in electricity reduction (-39%)	88	16
3	As scenario 2 plus 8 m^2 solar collector+600 l storage vessel, for DHW, space heating and hot fill	70	4
4	As scenario 3, heat pump instead of boiler	52	-

Table 5.3-2
Appliances and their electricity consumption in a Dutch household after two steps to save energy.

Most of the measures in scenario 2 fall under the first step of the Kyoto pyramid. The target of 75% reduction can be reached by adding 16 m2 of PV modules of optimum orientation.

In scenario 3, the area of the solar collector is increased from 3 to 8 m3 and the storage vessel from 0.15 to 0.6 m3. In this scenario only 4 m2 of PV are needed to reach the target. Finally, replacing the boiler with a high efficiency heat pump will help reach the target without the need for additional PV.

5.3.5 Conclusion

A reduction of 75% of the total (primary) energy consumption in a Dutch terrace dwelling appears very well possible with an integral approach based on the Passive House concept in combination with a solar collector to maximise the amount of passive and active solar energy. In addition, standby killers and application of A-label appliances substantially reduce electricity consumption. As a final measure, either 4 m2 of PV cells or a high efficiency heat pump will help reach the target. More innovative measures are being studied, but their effect is not included in this paper.

This project is supported by SenterNovem in the EOS-LT framework (Energy Research Subsidy, Long Term).

5.3.6 References

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6 Implementation of Solar Thermal Systems in Renovation

Thomas Mach, Richard Heimrath, Andreas Heinz, Angela Dröscher, Thomas Müller, Christian Fink

6.1 Approach

This chapter deals with the implementation of active solar thermal systems in building renovation. It references to miscellaneous experiences and research findings with a special focus on the results of the Austrian research programme "building of tomorrow":

More information at
www.hausderzukunft.at

Austria traditionally makes strong efforts to implement the thermal use of solar energy in the building stock. Due to a study of AEE INTEC (Institute for Sustainable Technologies) in Austria there was a total capacity of 251.9 kW_{th} per 1,000 inhabitants of glazed flat-plate and evacuated tube collectors in operation at the end of 2007 ([196] figure 5). This means that Austria comes third in the world (behind Israel and Cyprus) concerning the installed solar thermal power in relation to the number of inhabitants. The Austrian standing is documented impressively with the market enquiry ([162]) carried out every year on behalf of the Austrian Federal Ministry of Transport, Innovation and Technology (BMVIT [165]).

Due to this report the development of the solar thermal collector market in Austria is characterized by a strong increase of the sales figures of 25 % in 2008. In this year 362,923 m^2 solar thermal collectors were installed, which corresponds to an installed thermal power of 254 MW_{th}. 95 % of the installed solar thermal collectors were glass covered collectors for water heating and space heating. Considering the technical life span, in the year 2008 approx. 3.96 million m^2 of solar thermal collectors were in operation which corresponds to a thermal power of 2,775 MW_{th}.

For this reason Austrian solar thermal collectors produced 1,330 GWh_{th}, which causes a reduction of CO_2-emissions of 545,150 tons. The export rate of solar thermal collectors was 79.8% in 2007. The turnover of solar thermal industry was measured with 590 million Euros for the year 2008. Therefore approx. 7,400 full time jobs can be numbered in the solar thermal business ([164], page 3 and page 4).

From the economic point of view the solar thermal applications are economically competitive with other energy forms, especially because in all Austrian federal states the acquirement is aided by the public hand ([164], page 45). Rapid market increases could be recorded in the field of solar combisystems. In 2008 about 62 % of the new installed systems are used for domestic hot water and space heating and only 38 % were carried out solely for preparing domestic hot water. Solar thermal systems are already standard in many new buildings in Austria, even the percentage of implementation in the course of building renovation is increasing. In 2008 already 30 % of the new installed collector area was integrated in buildings as part of renovation measures (Figure 6.1-1).

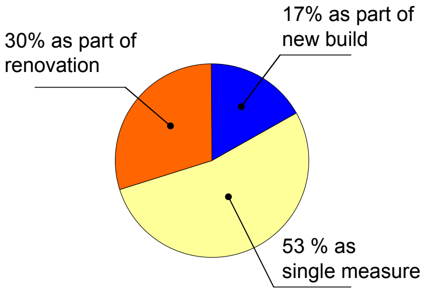


Figure 6.1-1
implementation of solar thermal systems in the Austrian building stock, related to the installed collector area in 2008 (362.923 m2) (data source: [164], page 43)

Focusing the observation layers

Due to the importance of the use of solar thermal heat use in new buildings the ambition to implement these in the renovation of buildings is the obvious next step of the ongoing development. To describe the different approaches and their obstacles in utilizing solar thermal energy in building renovation this chapter is structured by the concept of areal focusing the observation layers, which are, in a downsizing perception: region, settlement, building and component (Figure 6.1-2).

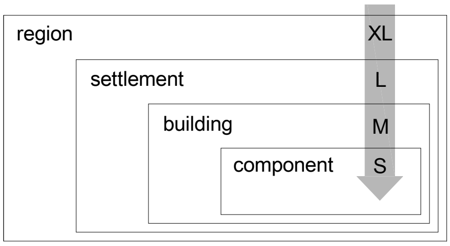


Figure 6.1-2
concept of areal focusing the observation levels for the implementation of active solar systems

6.2 XL - Region level

The transport of thermal energy always causes losses, long routes of transport should be avoided and therefore regional concepts should be preferred.

Local demand of thermal energy should be preferably covered by local supply of solar thermal energy. Currently a project named "ReCO2NWK" deals with this topic. Further information can be found in [189].

The principal idea behind this project is the development of a tool to meet a region's energy demand with locally available energy resources. Therefore a GIS (geographic information system)-based model has to be designed that can be used as a tool for estimation of possible coverage of the heating and cooling demand of a certain area with the local energy resources of solar thermal heat, geothermal heat and biomass (Figure 6.2-1).

6.2.1 GIS-based model of test regions

For the development of the model, two test regions in Styria, Austria have been chosen: the district of Murau, which is located at the border of the Alps and the districts of Feldbach and Radkersburg that are located at the foothills of the Alps. These two test regions are related by means of their size, but they differ significantly regarding their topography and consequentially their settlement and population structure. These spatial characteristics have a strong impact on both the structure of the energy consumption and the local energy resources, therefore the comparison of these two regions was considered especially interesting.

Because of the different structures of the test regions, the model has to deal with different boundary conditions for each region which has the advantage that the transferability of the model to differently structured regions is evaluated at an early stage. For the spatial model, a grid with 250 m cell width is applied on the investigation area. For each cell, the current energy demand for space heating and cooling, domestic hot water preparation and process heat per month is determined as well as the local potential to cover this demand with solar thermal heat, biomass, and geothermal heat (by the use of a heat pump). A monthly resolution is chosen for the model since both, the demand and the potential, differ strongly in the course of the year. For each cell and each month, the results of the demand model and of the potential model are then opposed to each other and the possible coverage of the energy demand with local resources can be derived. As the model is GIS-based, the spatial context of the cells persists and the cells can be clustered in order to arbitrarily expand the area that shall be evaluated by means of its local energy resources. For the modelling of the energy demand, the building stock has to be evaluated both by means of its structure (geometry, insulation) and its energy supply and distribution system. Information about the energy supply and distribution system is crucial because the factor between net energy and final energy strongly depends on it.

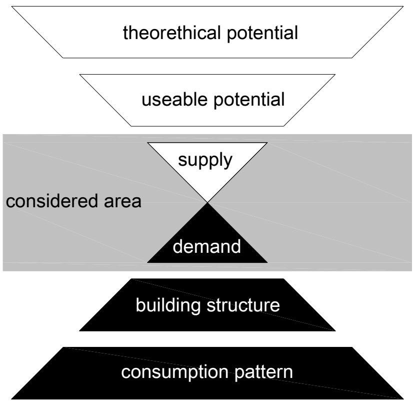


Figure 6.2-1
selected workflow approach

The potential of local energy resources can be defined in different ways since it is always a matter of technical, economic and also legal restrictions. For example, protection forests must not be used for biomass production, the installation of a solar thermal system too far away from the consumer is not reasonable (the same applies for a heat pump), neither the installation of e.g. a heat pump in a building with an inappropriate heat distribution system. Then the spreading of a certain technology is also dependent on the price development of the competing technologies and on the other hand it may be pushed with subsidies. For these reasons, costs have also to be considered in the model in order to provide a tool for creating realistic scenarios of energy supply. Another aspect of interest is the CO_2-balance that results from the different scenarios. When a CO_2-equivalent is assigned to each energy source and technology, this balance can also be calculated.

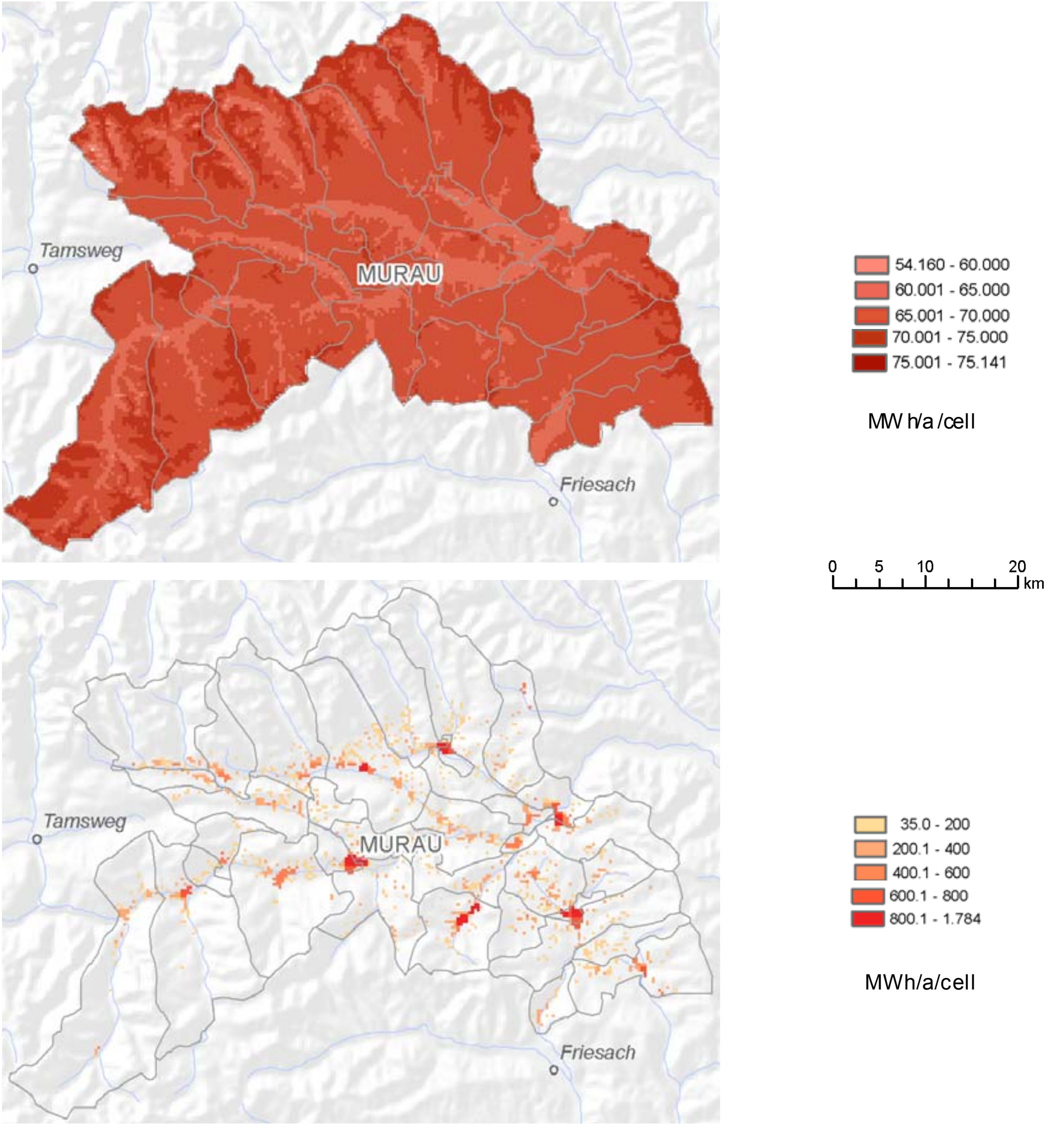


Figure 6.2-2
theoretic solar energy irradiation potential of test region Murau, image source: [189]

6.2.2 Solar thermal potential of a region

For the modelling of the local energy potential, several parameters have to be considered. For example the theoretic solar thermal potential of a cell is assumed to be the total global radiation on the sloped surface (the angle depends on the application either for only domestic hot water preparation or for a solar combisystem) within one cell (Figure 6.2-2). This value depends only on the geographic location of the cell.

The spatial information is stored in the GIS and out of that the monthly sum of global radiation can be calculated. This can be done according to the climate model described in ÖNORM B 8110-5 ([176]), or based on the climate data provided by the World Radiation Data Centre [197] or measured data can be used as well. For the useful solar thermal potential, the useable area is narrowed to suitable roof areas (which corresponds to the restriction named above regarding the distance between the place of energy production and the consumer). In order to make the result from the potential model comparable to the result from the demand model (the net energy demand), the useful thermal potential is further reduced by a system efficiency factor. This factor is strongly dependent on the system configuration, however, it may be assumed to be constant for a first rough estimation. In the same manner, the local potential of biomass and geothermal heat can be evaluated.With this approach it is possible to estimate the feasibility of covering the heating and cooling demand of a region with local resources of renewable energy and to figure out scenarios both of the demand and the potential that regards possible future developments of a region. Measures (e.g. subsidies) can be planned and their effect on the demand and the useable potential can be estimated.

6.3 L - Settlement level

Thinking about implementation of solar thermal use in the district heating of settlement structures first the question about locating the collector fields and storage systems are arising. The corresponding concepts can be divided in concepts organized centrally and concepts organized semi centrally.

6.3.1 Centrally organized solar aided district heating

In the last decade in Austria hundreds of centrally organized biomass fired district heating networks have been installed. One basic challenge with regard to such systems is the operation during summer time, when the heat demand is reduced to the domestic hot water preparation (in most cases about 5-10 % of the design capacity). This reduced heat demand leads to high specific net losses, which cause high specific emissions and costs. One way to overcome this problem is the implementation of a solar thermal system.

For constructors and operators of district heating networks and for the funding agencies, the question arise, under which circumstances the combination of solar thermal energy and biomass fired boilers makes sense from an economical and ecological point of view compared to other concepts, which have to provide heat in summer without solar supply. The research project "Solar Assisted Heating Networks" was focused on this question. Further information can be found in [190]

Within the project centrally organized solar aided district heating systems were analysed. These systems consist of one ore several central field(s) of thermal collectors connected to one central storage system and one central system for auxiliary heat production. These centrally positioned components supply the heat demand of the joined buildings through a network of pipes. An example for the adding of a solar thermal system to an existing biomass district heating system can be seen in Figure 6.3-1. In this research project a criteria check list for system attributes was developed. Depending on the plant size, the plant design, the type and amount of subsidies and other system attributes, the criteria check list offers an economic and environmental assessment. This can be used for a decision-making, whether the considered combination of biomass boiler and solar thermal heating system is economically and ecologically competitive.

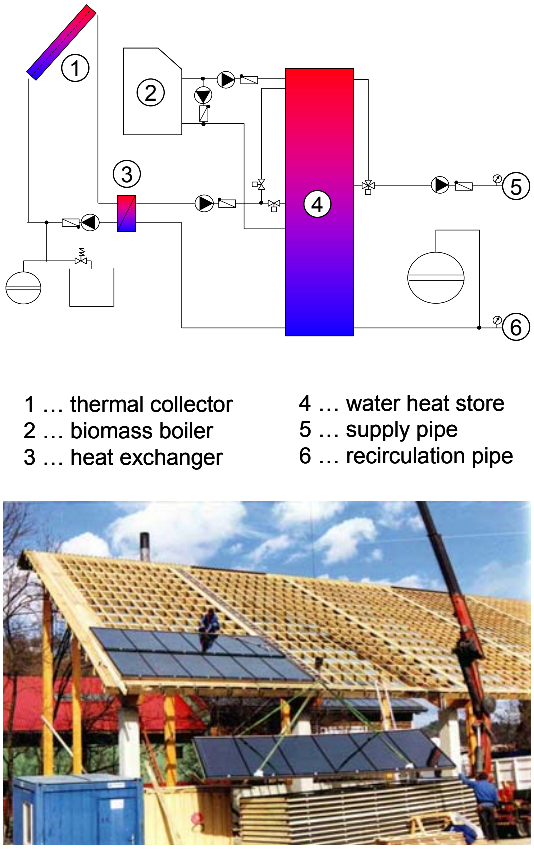


Figure 6.3-1
hydraulic integration of solar thermal components in the district heating system in Eibiswald (on the top) and mounting of large scale collector modules,(data source:[192])

The results of the project are based on an extensive data acquisition for biomass local district heating networks with and without solar plant in Austria and thermal simulations of four reference systems with different configurations, heat loads and sizes in numerous scenarios. Subsequently an economic analysis was carried out using the annuity method according to VDI 2067 ([195]). Beside manifold calculation results the following findings were obtained.

Heat load density - In the course of the data acquisition detailed data of 65 district heating plants could be obtained.

The results showed that the total investment costs of a district heating network are highly dependent on the heat load density (heat demand compared to the length of the heating network). It was, however, stated that a majority of the district heating networks have a low heat density of partly far below 1000 W/m.

Return temperature of the network - For the economy of a combination of biomass and solar plant low return temperatures which allow high specific energy savings by the solar system are an advantage. It was also found, that the summer operation with a solar plant is economically competitive in comparison to a summer operation with an oil boiler, which is often done in Austrian biomass district heating plants. With regard to a summer operation with biomass fuels the result depends strongly on the kind of biomass used in the respective case.

Size of boiler - The implementation of solar thermal systems in the centrally supplied heating networks allows a significant reduction of the primary energy consumption. Regarding the emission savings potential there is a high dependency on the respective boiler dimensioning, due to the increased emission output of boilers in cycling operation, which was considered in the calculations [190].

Summarising it must be said that the thermal rehabilitation of the in such a way supplied building stock lead to a decreased heat density and therefore a reduced operating efficiency. If, however, a complete thermal rehabilitation of the entire service area can be reached, the supply temperatures can be reduced and a higher fraction of solar coverage can be achieved.

Example for realisation of solar thermal energy in a district heating network

In 2002, in Graz, the first feed-in of solar thermal energy in a district heating network was brought on line. The collector field (1,407 m²) is mounted on the roof of a skating hall (Figure 6.3-2, top Figure). The plant is operated by means of contracting. In 2008, a second solar feed-in was finalised at the premises of the waste disposal and recovery GmbH (AEVG) and the adjacent district heating power station Graz-Süd (Figure 6.3-2, mean Figure). The largest solar array in Central Europe (4,062 m²) is placed on four separate roofs. In 2009 a third solar thermal direct feed-in of solar thermal energy into the district heating grid of Graz was brought on line (Figure 6.3-2, bottom Figure). The 3,855 m² collector field is combined with a water heat store (heating support utility) of 64.6 m³. The described facilities were designed and constructed by the company SOLID ([192]).

Figure 6.3-2
facilites for feeding-in solar heat in the district heating network of Graz, data source: S.O.L.I.D [192]

Collector area: 1407 m² (large scale collectors)
application of energy: about 540 MWh/a
initiation 2003

Collector area: 4062 m² (2008)
Planed enhancement: up to 6903 m²
application of energy: about 1.800 MWh/a
initiation: 2007-2008

Collector area: 3855 m² (complete assembly in 2010)
Store volume: 64.6 m³
district heating feed–in and heating support
Commissioning: 2007-2008

6.3.2 Semi centrally organized solar aided district heating

In densely populated areas, the net-bound heat supply plays a decisive role. In urban areas long distance heating systems are common. In areas with a rural characterisation rather local district heating systems are favoured. Small versions of local district heating systems, so called micro networks show a high potential for efficient heat supply of small area settlements. If these networks are based on renewable energy sources (biomass and solar thermal) they could, compared to individual supply, make a significant contribution to the reduction of CO_2 emissions in the sector "space heating and domestic hot water" and additionally offer an increased level of supply guarantee. Micro networks can be used for new housing estates as well as for settlements to be renovated.

Difficulties of implementation

Despite their apparent potential they could not be established as a standard heat supply system in Austria in the last few years.

The attempt to find an explanation for this development leads to technological, economical and organizational obstructions concerning the implementation of micro networks. Typically a new build settlement is realized step by step in several implementation phases. In many cases the construction is a process which could last a couple of years, up to decades. The heat engineering and regulatory requirements could change several times. According to this the supply system has to be constructed in a modular and adaptable structure.

The project "Heat supply of development areas through supplementary solar supported near heat nets" is focused on the technological aspects of this problem. Further information can be found in [179]. The specific objective of the project was to find solutions for efficient network configurations, which work on the base of decentralized load balancing stores and decentralized injection points for solar heat, including the dimensioning of all technological components. Additionally a comprehensive cost analysis for modular heating networks in comparison to decentralized, conventional heating systems had to be done.

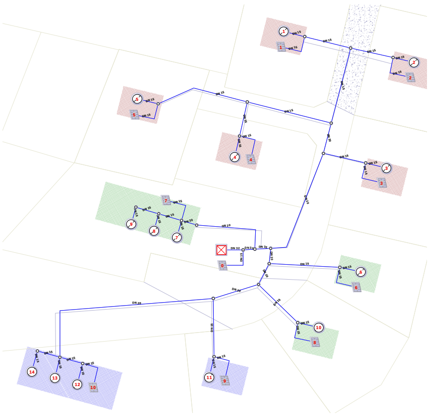
The first step was a data search and a survey concerning the current and future anticipated structure of settlements. Based on this preliminary work, three typical settlement areas were defined (Figure 6.3-3). The colours mark the phase of implementation: red marks the buildings of the first phase, green marks the buildings of the second phase and blue marks the buildings of the third phase. All three settlements have been thermo technical modelled in a combination of the TRNSYS simulation environment ([194]) and the network calculation program simplex ([171]).

Figure 6.4-2 shows some basic design figures of the settlement models according the accommodation units, the erecting time per phase and some key figures about the grid. Figure 6.3-5 shows a cross section of two pipes, analysed due to their thermal losses.

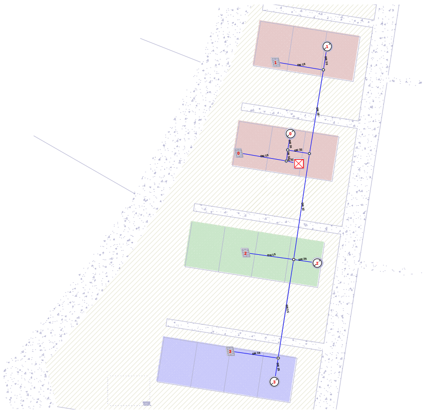
In addition, the accumulated total costs (Investment cost plus operating costs) for the three designed settlement areas were calculated for a period of 25 years. The calculations are based on the following economic assumptions:

- External financing, interest rate: 5 %
- Energy price increase per year: 4 %
- Efficiency of the boilers depending in the energy source: 80-85 %

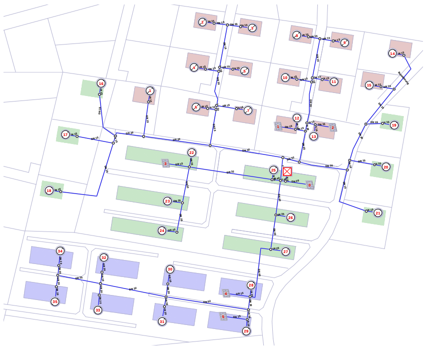
Figure 6.3-3
sketches of the developed settlement and grid structures, the colours mark the phase of implementation: blue: first phase,
green: second phase, red: third phase, image source: [180]



Single family house area
14 accommodation units
100 kW heating load



Multi family house area
34 accommodation units
150 KW heating load



Mixed area (multi family houses, row houses and multifamily houses)
117 accommodation units
600 KW heating load

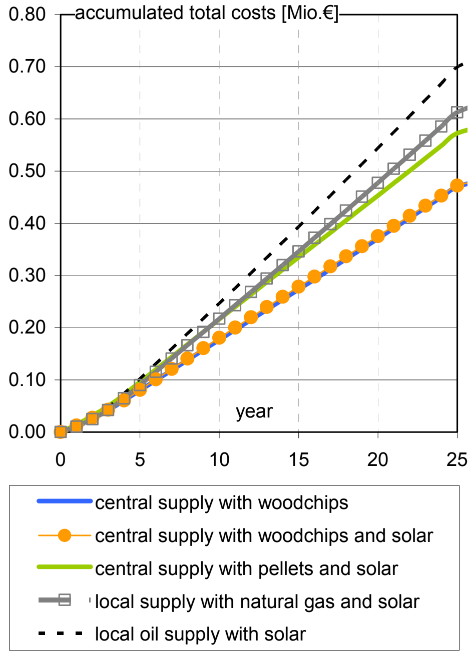


Figure 6.3-4
accumulated cost for the heat supply in the multi family house area, assumed prices:
woodchips: € 0.029/kWh,
wooden pellets: € 0.053/kWh,
natural gas: € 0.061/kWh,
oil: € 0.064/kWh,
data source: [180]

Basically the project results show that an integration of solar thermal systems in micro-networks reduces the total cost, if an expensive fuel is substituted (natural gas, oil). For cheaper fuels (wood chips) the integration of solar energy is expected to be neutral. In matters of ecology the integration of solar thermal energy in micro-networks can always be seen as an advantage.

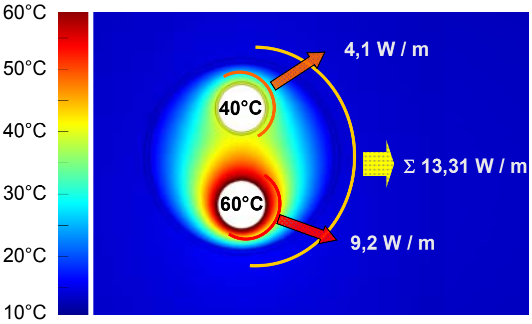


Figure 6.3-5
enquiry of the thermal losses of the pipes in the supply network,
image source: [180]

6.4 M - Building

Even though thermal systems show a far bigger economic potential in the field of renovation the market development of solar thermal systems in the existing building stock is considerably slower than it is in the sector of the new buildings. In comparison to the integration into new buildings some technical and organizational differences have to be taken into account. First the best time of implementation, has to be chosen, then the collectors have to be integrated in buildings which were originally not designed for this purpose. Finally the implemented system has to be integrated in the existing distribution network (2 pipe net versus 4 pipe net). Basic principles are described in the following.

6.4.1 Time of Implementation

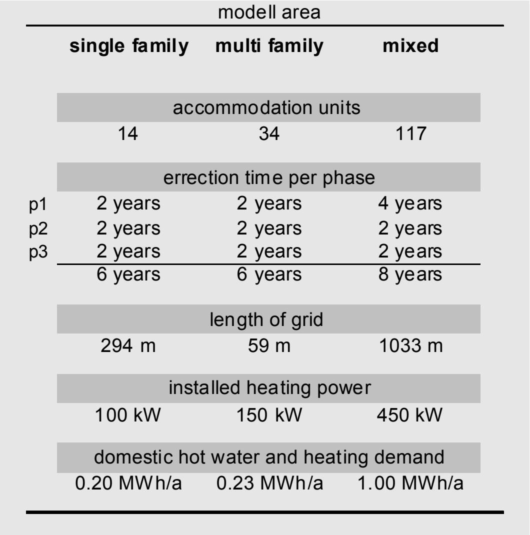
To keep the investment costs as low as possible, some convenient times have crystallized for the additional integration of solar thermal systems, in which the best time appears for the integration of a solar thermal system within the framework of a comprehensive (total) modernization (upgrading). By an integral consideration the highest possible efficiency can be achieved at comparatively favourable (beneficial) investment costs. The replacement works on the domestic hot water preparation and the heating system or the repair works on the roof (parts of the roof cover can be taken by the solar thermal system) are for example most suitable times. If synergies can be achieved, then the investment costs for the solar thermal system are below or within the same range as in the case of the new building.

6.4.2 Placing the solar collectors

The integration of solar collectors in the envelope of an existing building leads to two main questions. On the one hand the collector fields have to be integrated in the architectural design concept of the whole building and on the other hand the collectors have to achieve a high energy yield to be economic profitable.

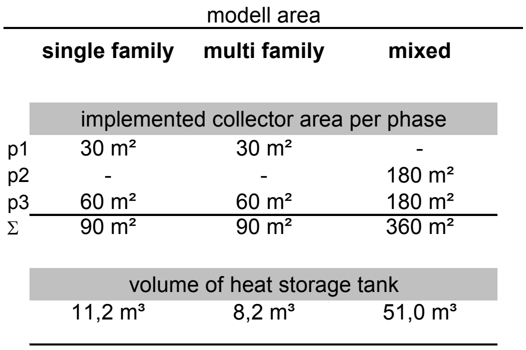
Construction and visual design

The basic design problem of the integration of thermal collectors in existing building envelopes in the course of a renovation is based on the fact that the original design concepts did not include this purpose. Therefore, when it comes to applications of solar space heating in building renovation projects there are often sufficient and suitable and oriented roof areas available for the installation of solar collectors. When installing these on existing roofs or joining them to flat roofs, the plants often form a foreign body since they are not an integral part of the architecture.



	modell area		
	single family	**multi family**	**mixed**
	accommodation units		
	14	34	117
	errection time per phase		
p1	2 years	2 years	4 years
p2	2 years	2 years	2 years
p3	2 years	2 years	2 years
	6 years	6 years	8 years
	length of grid		
	294 m	59 m	1033 m
	installed heating power		
	100 kW	150 kW	450 kW
	domestic hot water and heating demand		
	0.20 MWh/a	0.23 MWh/a	1.00 MWh/a

Figure 6.4-2
design proposals to achieve the economic optimum,
data source: [180]



	modell area		
	single family	**multi family**	**mixed**
	implemented collector area per phase		
p1	30 m^2	30 m^2	-
p2	-	-	180 m^2
p3	60 m^2	60 m^2	180 m^2
Σ	90 m^2	90 m^2	360 m^2
	volume of heat storage tank		
	11,2 m^3	8,2 m^3	51,0 m^3

Figure 6.4-1
design proposals to achieve the economic optimum,
data source: [180]

For this reason solar plants are still rejected by many architects and town planners. To overcome these obstacles the solar industry increasingly provides products to raise the variety of construction possibilities and visual design options. A description to this ongoing development is given in the chapter named "S - Component level".

Energy gain

The basic motivation to implement solar collectors lies in the gaining of energy. The amount of solar energy that can be obtained is closely linked to the location and position of the collector itself. **Fehler! Verweisquelle konnte nicht gefunden werden.** and Figure 6.4-3 give an impression of the importance of the placing.

It has to be taken into account that the solar collectors are often shaded in some way. Therefore the irradiation that is characteristic for a combination of location, angle of incidence and direction of incidence is reduced. Especially when placing solar collectors in inter-urban areas this aspect has to be considered.

Example for the implementation of collectors on the flat roof

The Lower Austrian property developer GEDESAG [168] focuses not only on integral technical building concepts in the new building. But also in the building stock the use of solar thermal energy pushed is backed strongly as numerous realized examples of the company show. It is a central request of the property developer in the context of a global building renovation concept that in the course of adaption the building automation also to integrate solar thermal systems into the heat supply.

Besides the integration into the building automation it applies also the building integration of the collectors (saddleback roof integration, flat roof installation, façade integration, design as balcony or parking place roofing etc.) according to the conditions as well as also the resident wishes with maximum energetic efficiency and a nicely shaped implementation. Exemplarily in two projects of the GEDESAG different approaches for the integration of the solar thermal plant were carried out:

	irradiation in kwh/month				
	roof				facade
angle	0°	30°	45°	60°	90°
south					
jan.	34	60	68	72	68
feb.	54	78	84	86	75
mar.	93	118	122	119	95
apr.	119	130	127	117	83
may	158	160	149	132	82
jun.	160	156	143	124	75
jul.	164	162	150	131	81
aug.	143	153	146	133	90
sep.	102	122	122	117	89
oct.	70	98	105	106	91
nov.	37	62	70	73	68
dec.	28	49	55	59	56
Σ	1162	1346	1341	1268	953
east / west					
jan.	34	33	32	31	25
feb.	54	49	46	43	34
mar.	93	88	83	76	59
apr.	119	113	105	96	73
may	158	149	139	127	97
jun.	160	153	142	129	96
jul.	164	154	143	131	98
aug.	143	133	124	112	84
sep.	102	95	90	83	65
oct.	70	64	60	56	44
nov.	37	33	32	30	24
dec.	28	25	24	23	18
Σ	1162	1090	1020	936	716
north					
jan.	34	14	14	13	11
feb.	54	24	22	21	17
mar.	93	50	33	31	27
apr.	119	85	63	46	37
may	158	126	100	71	49
jun.	160	135	112	85	54
jul.	164	136	112	84	55
aug.	143	106	80	56	43
sep.	102	63	42	36	31
oct.	70	31	27	26	22
nov.	37	16	15	14	12
dec.	28	13	13	12	10
Σ	1162	799	634	494	368

Figure 6.4-3
*irradiation on different orientations and angles of incidence **
** Data source Meteonorm [194], climate data of Graz calculated with TRNSYS [194]*

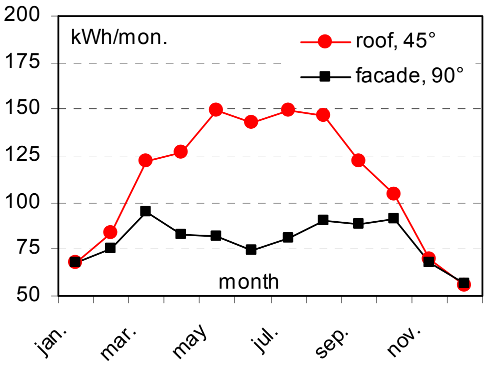


Figure 6.4-4
*radiation on a roof versus radiation on a vertical façade, both facing south**
** Data source Meteonorm [174], climate data of Graz calculated with TRNSYS [194]*

In Lower Austria in the city of Krems (Mitterauerstraße) a global building renovation of a multifamily house was done. In the course of this renovation (window exchange, flat roof refurbishment incl. insulation, renewal of the heating control centre incl. domestic hot water preparation, elevator installation, Grander water revitalization, outside facilities etc.) a solar thermal system was built for the domestic hot water preparation of the 80 freehold flats.

The collectors are practically not visible for the residents. In this project a combined renovation of the flat roof (erection year 1969) and the installation of the 188 m² large solar thermal plants were carried out. The installation of the collector supporting structure could be carried out in the course of the insulation- and sealing work. Another synergy effect with the solar thermal plant erection was given by the installation of the heating control centre (condensing gas boiler instead of old gas boiler) respectively the domestic hot water preparation.

Since the heating control centre is situated at the flat roof and the heat distribution runs from the roof in the direction of the ground floor centrally (four pipe net), the solar energy storage tanks (altogether 12 m³) were also put in the attic storey which interfere with effects on the static assessment of the sub-construction. The annual solar fraction of the domestic hot water need lies within the project "Mitterauerstraße" according to information from the project managers at the GEDESAG at about 60 %. The specific investment costs for the solar thermal plant are about 550.-€/m² collector area, which results in a payback period of about 11 years. The costs for all concluded redevelopment measures amounted to 104.-€/m² living area in the concrete project with a simultaneous reduction of the original heat requirement by more than 30 %.

Example for collectors implemented in the façade

A very striking building integration was chosen by façade integration was carried out in the project "Admonterstraße". A 90 m² solar thermal collector area at the south façade is used for the domestic hot water preparation for 30 rented apartments. The main advantages of this kind of integration are the reduced investment costs (as no stilting construction is necessary) and the enforced identification of the residents with the solar heating system. Disadvantages in form of yield losses (primarily in the summer months) arise at a façade integration because of the collector areas are inclined to 90°. A little longer amortization time period (about 16 years) is the consequence out of this in this example. The installation of the solar heating system was embedded in a comprehensive building renovation (window exchange, flat roof renovation incl. insulation, façade insulation incl. balcony renovation, cellar ceiling insulation, electrical installations, outdoor facilities, etc.) in this project.

Figure 6.4-5
Striking and well designed integration of 90 m² of solar thermal panels into the building façade of the object "Admonterstraße", Krems, image source: GEDESAG [168]

Figure 6.4-6
Altogether 12 m³ energy storage volume in the heating control centre of the flat roof, image source: GEDESAG [168])

Figure 6.4-7
188 m² collector area at the flat roof of the object "Mitterauerstraße" managed by the GEDESAG, Krems, image source: GEDESAG [168]).

The complete building renovation costs for the project "Admonterstraße" amounted to 213.-€/m² living area.

Hydraulic integration of solar thermal systems in the course of a building renovation

Depending on the composition of the existing heat production for domestic hot water and space heating (central or decentralized) and the aspired functionality (domestic hot water preparation or solar combisystem) basically three different types for the hydraulic integration of a solar system are given.

6.4.3 Solar thermal domestic hot water supply with four pipe net

Building stock (initial position): the object has a central heating supply system for the space heating and domestic hot water preparation (dhw). The heat distribution (room heating and dhw) is carried out via one pipe pair each (four pipe net).

Integration of solar thermal systems

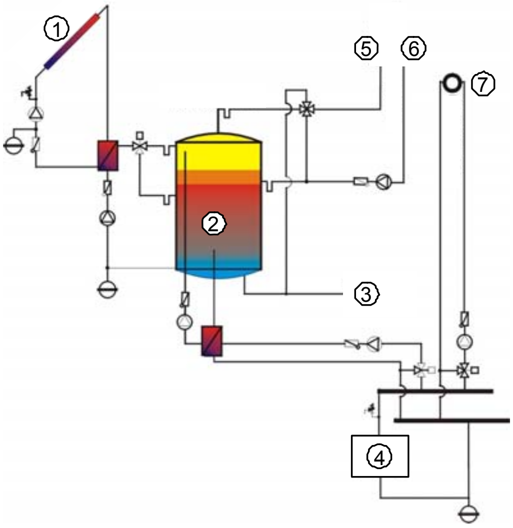
The existing domestic hot water system (drinking water storage or a big fresh water module) is extended with an energy storage (at small applications one drinking water storage, at greater applications a buffer storage) up streamed, which is charged by the solar thermal system. The coupling is simply, economically and in principle always possible. If the solar plant also is integrated in the room heat supply, heat generation and space heating system are also coupled hydraulically to the energy storage.

Technical description of the solar thermal system

The collector array is connected via an external heat exchanger to a new domestic hot water tank. The solar loop has the possibility to stratify via two different heights into the dhw - tank (depending on the temperature from the solar heating system). If the energy input from the solar heating system is not enough, the existing heating system has to deliver heat with sufficient temperature. For the optimal operation of the solar heating system it is necessary to think about the best position of inlets and outlets of the dhw - tank. Hot solar inputs, the always hot standby volume and also the inlet position of the dhw circulation pipe should be carefully positioned. For the heat distribution the two existing pairs of pipes are used. The needed temperature level for the space heating pipe pair is depending on the used space heating system (radiator or floor heating) but after a building renovation in the most cases temperatures below 55 °C supply and 45 °C return temperature must be possible.

The domestic hot water pipe pair requires supply temperatures above 65 °C and comes back with return temperatures of about 55 °C. With these high return temperatures, this concept can not reach a maximum system performance. Detailed information's about the solar thermal domestic hot water preparation with four-pipe nets can be found in the projects [190] and [191].

Figure 6.4-8
Afterwards installed solar thermal system (collector area 320 m²) on the flat roof of a housing department in the Hans Riehl Gasse in Graz, supply into the central domestic hot water preparation, image source: [192]



1 … thermal collector
2 … hot water tank
3 … cold water
4 … boiler
5 … hot water
6 … domestic hot water circulation
7 … domestic space heating

Figure 6.4-9
Hydraulic schematic of a solar thermal domestic hot water preparation with a four pipe net

6.4.4 Solar thermal heat supply with four-pipe net

Building stock (initial position): the considered object is equipped with a central room heat supply (ascending pipe break through apartment boundary (border)) and about a decentralized domestic hot water preparation (off peak storage or instantaneous gas-fired heater).

Integration of solar thermal systems

The heat distribution system is extended by a thermal energy store (buffer storage) which is charged by the solar thermal system and also by the conventional central heating plant. The space heating distribution is carried out to the apartments via the existing pair of pipes.

The domestic hot water preparation must be realized over a new pair of pipes (e.g. over the staircase house) in connection with fresh water stations. The existing domestic hot water system (off peak storage or instantaneous gas-fired heater) can be replaced with fresh water stations (domestic hot water preparation in the flow principle) which can be coupled to the apartment internal domestic hot water distribution system with low adaptation work. Besides the possibility of using solar energy these hydraulics also offer advantages with respect to user comfort and water hygiene. If the object is modernized extensive, it has to be checked if a general installation of the heat distribution system according to the principle of the two-pipe net with tap water stations and apartment internal supply could be more useful. The heat distributing losses also could be reduced considerably through this measure.

Technical description of the solar thermal system

The collector array is connected via an external heat exchanger to a new energy storage tank. The solar loop has the possibility to stratify into the energy tank via two different heights (depending on the temperature from the solar heating system). If the energy input from the solar heating system is not enough, the existing heating system cares about the temperature specification for the standby volume within the upper part of the energy store. For the optimal operation of the solar heating system it is essential to think about the right position of inlets and outlets of the heat storage. The hot solar inputs, the always hot standby volume and also the inlet position of the room heating and dhw preparation return pipe should be carefully attended. For the heat distribution one existing (space heating) and one new pair (dhw) of pipes are used. The needed temperature level for the space heating pipe pair is depending on the used space heating system. Temperatures below 55 °C supply and 45 °C return temperature are possible.

The new domestic hot water pipe pair needs supply temperatures around 60°C and returns with temperatures below 30°C. With this low return temperature (dhw preparation), this concept can reach higher system performance then the concept before. Detailed information’s about the solar thermal domestic hot water preparation with four-pipe nets can be found in the project [190] and [191].

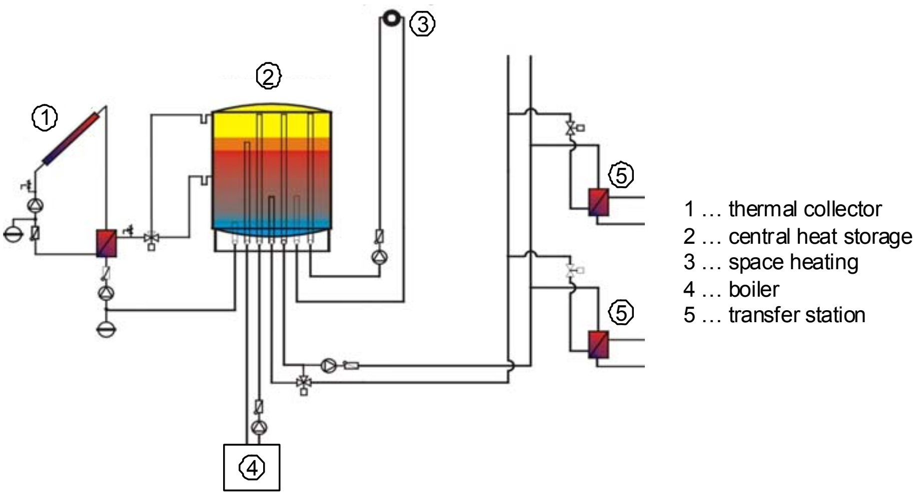


Figure 6.4-10
Schematic of a solar thermal heat supply with a four-pipe net

6.4.5 Solar thermal heat supply with two-pipe net

Building stock (initial position): the considered object is equipped with decentralized room heat supply (individual stoves, heating system covering one floor) and decentralized domestic hot water preparation (off peak storage, instantaneous gas-fired heater or energy storage in combination with self-contained central heating).

Integration of solar thermal systems

Beside the integration of a solar thermal system a switch from a decentralized supply

Figure 6.4-11
In the course of a complete modernization a solar thermal system (with 164 m² collector area) was installed at the Plainstraße (Salzburg). The non-profit housing company gswb [168] realized there the heat supply concept with a two-pipe system with apartment stations (42 flats).

to a centralized heat distribution system will be done. Figure 6.4.-9 shows an example for an building modernization including a solar heat supply with a two-pipe net.

Both, solar plant and conventional heat generation system, charge a central energy storage from which the heat supply (domestic hot water and room heating) is carried out via a two-pipe net, which is newly installed. If the building stock is supplied via a heating system covering one floor, the existing, apartment internal heat distributing system can be used for the room heat supply. If individual stoves (wood, coal, electrical etc.) become substituted, the room heating supply must be installed newly.

The existing domestic hot water heater will be replaced by apartment stations or fresh water stations (domestic hot water preparation in the direct flow principle) which can be coupled to the existing internal domestic hot water distribution system with low adaptation work. Besides the possibility of using solar energy, this system also has advantages in terms of user comfort, water hygiene and minimized thermal losses.

Technical description of the solar thermal system

The collector array is connected to a new energy storage tank via an external heat exchanger. The solar loop has the possibility to stratify via two different heights into the energy tank (depending on the temperature from the solar heating system). If the energy input from the solar heating system is not enough, the existing heating system care about the temperature specification for the standby volume within the upper part of the energy store (lower part is exclusive for the solar heating system). Figure 6.4-12 shows a schematic drawing of the described concept.

For the optimal operation of the solar heating system it is necessary to think about the right position of inlets and outlets of the heat storage. The hot solar inputs, the always hot standby volume and also the inlet position of the return pipe should be carefully attended. For the heat distribution is only one pair of pipes used. The needed temperature level is depending on the used space heating system (radiator or floor heating) but in the most cases 60 °C supply and 30 °C return temperature. With this concept it is possible to realize a maximum of solar fraction, because of the low return temperatures into the heat storage (ideal for the solar thermal system). Detailed information’s about the solar thermal heat supply with two-pipe nets can be found in the project [190] and [179].

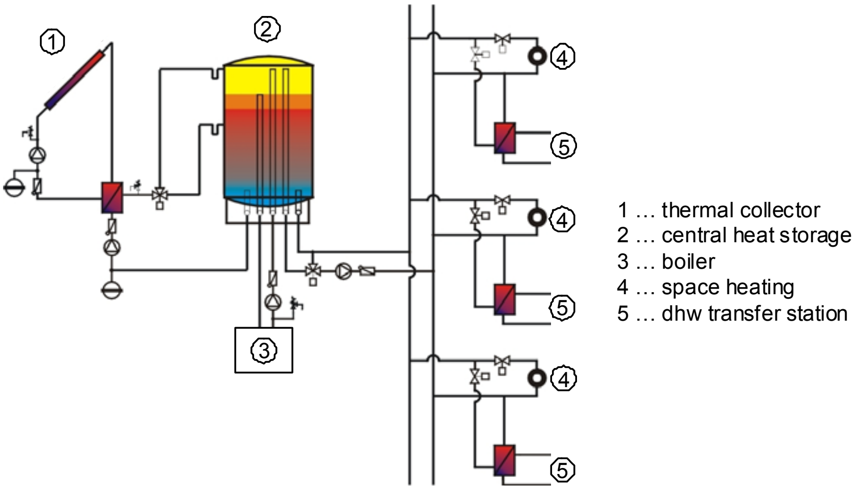


Figure 6.4-12
Schematic of a solar thermal heat supply with a two-pipe net

6.4.6 Control and Monitoring

A solar thermal system is designed to work efficiently under certain operating conditions. However, in practice, unexpected conditions may occur and the components will be affected from material aging and fouling. The consequences are lower solar gains and finally, in worst case, the breakdown of the solar thermal system.

In practice, many malfunctions and failures in the system remain undetected until the worst case comes to pass. However, the efficiency of the solar thermal system is reduced from the time the failure occurs and possible solar gains are wasted. The bigger part of those malfunctions can be detected at an early stage, when the solar thermal system is monitored and maintained permanently. Annoyance and costs can be saved when the failures are detected and resolved shortly after their occurrence. The reason why the necessary monitoring for early failure detection is usually not carried out is the high time and consequently cost effort for the monitoring task. Until now, no standardized monitoring concept has been established and hence each solar thermal system has to be handled individually.

Within the R&D-project "IP-Solar" [182], an approach to efficiently deal with the monitoring task is developed. The goal is a monitoring tool that has a high automation

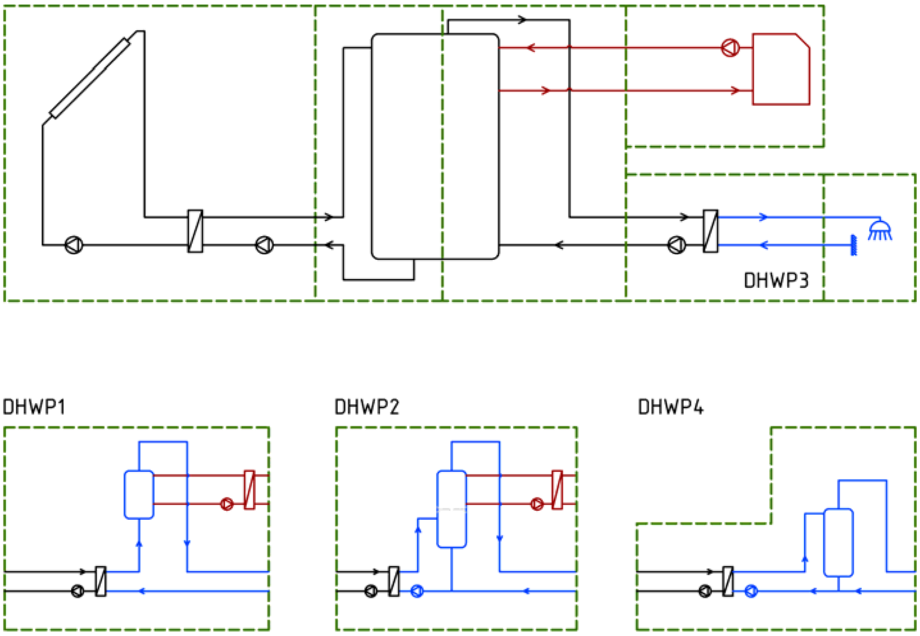


Figure 6.4-13
Modular design of a solar thermal system for dhw preparation, image source: [182]

level but is still flexible and applicable on different solar thermal systems (no commitment to a certain producer or operator).

The basis for a standardized monitoring concept is a standardized hydraulic concept of solar thermal systems. To evaluate common hydraulic configurations, a market analysis of solar thermal systems in Central Europe with more than 80 m² collector area has been performed. The focus was set on the hydraulic design as well as on the measuring and the control concepts. Based on this study, standardized modules of a solar thermal system have been defined. Figure 6.4-12 shows an example of a solar thermal system for domestic hot water preparation that is built from predefined modules (dashed lines = module boundary). Thanks to the modular design, differently configured solar thermal systems can be described by assembling the appropriate modules. The second row in Figure 6.4-12 shows three other variants of the domestic hot water preparation module (DHWP) that can replace the module variant DHWP3 in the upper row. For every module, several compatible variants are predefined in a database that is extendable for future developments.

Corresponding to the modules, a recommended minimum measuring concept is defined as well as several other possible measuring concepts. With those prerequisites (standardized hydraulic configurations and measurement concepts), the intrinsic objective, the development of an automated monitoring concept, can be treated. At present, the algorithms for failure detection and identification are worked on. The monitoring tool is supposed to give assistance in ensuring permanently efficient operation of the solar thermal systems that are conceived in new buildings as well as in renovation projects.

6.5 S - Component level

With regard to the component level a whole bunch of questions is connected to the intention to comprise solar thermal systems in the renovation processes of buildings. In each project a large variety of components has to be chosen or designed. In the following selected components and several research projects which are concerned with these topics are described.

Figure 6.5-1
202 m² collector area on a roof of a multifamily building in Vienna (Erlaaerplatz), 200 apartments,10 m³ heat store, Copyright: S.O.L.I.D.[192]

6.5.1 Constructional integration of thermal collectors

Pertaining to the integration of solar collectors in to be renovated building envelopes the constructional integration must be solved. In case of placing the collectors outside the thermal building envelope fixed with self-contained mounting systems basically mechanical requirements for the collector and the fixing system have to be fulfilled. Examples for this are the mounting outside of on a steep roof close to the roof covering (Figure 6.5-3), elevation on the top of flat roofs (Figure 6.5-1) or the mounting of the solar thermal collectors on open adjoining buildings like car ports (Figure 6.5-2).

When installing collectors on existing roofs or joining them to flat roofs, the plants often form a foreign body since they are not an integral part of the architectural design. For this reason solar plants are still rejected by some architects and town planners. For a wide market penetration it is, therefore, necessary to use collector systems which allow the integration of the collectors in building envelopes (roof or façade constructions).

In the case of integration of the solar thermal collectors in a building envelope additionally to the mechanical requirements further requirements in terms of building physics have to be fulfilled. For example fire resistance of the covering and the fixing system, as well as heat and noise protection of the whole constructional element have to be fulfilled. In the field of moisture proofing rear ventilated or not rear ventilated concepts are in opposition to each other.

Following the classical rules of building physics the resistance against humidity should decrease following the construction layers from inside to outside. But this disagrees with the covering of the collector which is made of glass and therefore nearly impenetrable for vapour. For this reason a gap between the collector and the wall provides air ventilation which is removing moisture. The disadvantage lies in reduced heat protection of the construction because of the ventilation. During the heating season in not ventilated constructions the heat losses are reduced because of the higher temperature in the collector. On the other hand this leads to heat transfer to the interior room. This effect could cause increased temperatures or cooling loads in the interior room in the cooling season. Figure 6.5-7 shows a typical example for the implementation of big scaled solar collectors in renovation projects of apartment houses. The integration of solar thermal collectors in roof constructions based on commercially available appliances can be considered as state of the art in the market for several years and examples for implementation in renovation processes are wide spread.

For large-scale plants in urban building projects there are not always and sufficient suitable oriented roof areas available for the installation of solar collectors. As an alternative the mounting of solar collectors in vertical facades became more and more common. One pioneer of this development was the research project "Façade Integrated Solar Collectors" [183]. Within the framework of the project basic knowledge for the design and technical construction of vertical in façade constructions integrated solar collector fields was developed.

In the research project especially non rear ventilated directly integrated solar collector plants have been developed. In this context a collector element directly integrated in the façade is understood by the façade-integrated solar collector in which heat insulation is a component of the building as well as a component of the collector. There is no separation between in the form of rear ventilation between them. The collector which basically comprises of a fluid-cooled absorber behind a covering glass pane which is fixed by glass bearer profiles combines different kinds of functions:

- energetic converter - Function as a solar thermal flat plate collector
- heat insulation - The attainment of passive gains in the glass covered hollow space causes temporarily smaller heat losses through the exterior wall
- weatherproofing - The glass covering represents an excellent protection against atmospheric conditions

Figure 6.5-2
solar collectors build as outdoor car roofing for an apartment building in Graz (Grottenhofstrasse) Copyright: ENW Ges.m.b.H.

Figure 6.5-3
fixing of a solar collector close above the roof tiles of a steep roof, Copyright: GREENONETEC [169].

Figure 6.5-4
light metal façade with embedded solar collectors,, Copyright: GREENONETEC [169]

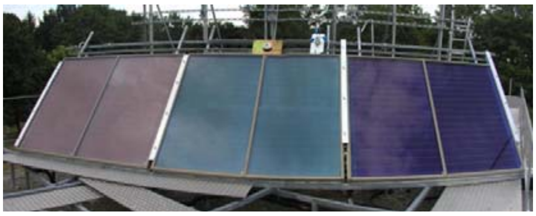


Figure 6.5-5
test rig, angle of inclination 45° (from left to right: auburn, green, selective coating of absorber), image source: [175]

color	glazing	conversion factors	efficiency T = 45 K
black selective	low reflecting	81.5	60.2
black selective	structured	79.7	58.4
blue	structured	77.7	46.4
green	low reflecting	75.5	46.6
auburn	low reflecting	71	44.8
auburn	structured	70.6	44.2
grey	structured	61.8	31.3

Figure 6.5-6
conversion factors and degrees of efficiency at a temperature difference of 45 Kelvin between ambient temperature and collector mean temperature,
data source: [178]

- design element - The visual appearance differs largely from conventional building envelopes

The project team made the following conclusions:

For a wide market penetration of solar thermal systems in retrofitting of buildings it is required that collector systems which can be integrated in façades are commercially available. As the development of façade systems for photovoltaic modules has shown, a large market segment can be opened.

In the design process architects and solar planners have to cooperate from the very beginning of a project to arrive at successful conclusions.

For systems with vertical collector plants less irradiation has to be taken into account compared to systems with collectors on an inclined surface.

A vertical collector has a better U-value than a tilted collector, because of the reduced heat losses of the collector due to the reduced convection between the absorber and the glazing.

If there is no rear ventilation between the collector and the wall construction, the U-value is lowered because of the minimization of heat losses to the backside of the collector.

The main question for collectors mounted on massive walls is the mounting of the collector without thermal bridges. When mounting collectors on massive walls it is important to take care of thermal bridges, otherwise heat losses of the building in the winter time are significant. Especially for light weight wall constructions the removal of the humidity is important. If the collector is mounted without an air gap for ventilation the construction must have the possibility to dry to the inside of the building. Therefore the inner layers of the wall must be open for vapour [183]. Figure 6.5-4 shows an example for the integration of solar thermal collectors in a suspended light metal façade.

6.5.2 Colour and shape of solar thermal collectors

The increase of design variety can be seen as a foundation of an intensified application of solar thermal collectors in building envelopes. In this context coloured absorbers are a major demand of architects especially for the design of façade integrated solar thermal collectors. However coloured absorbers have shown an inferior thermal performance compared to selective coatings of state-of-the-art collectors so far. Within the project “Colourface” [178] selective colour coatings have been developed and ageing tests of the coatings have been performed. The thermal performance of the different coloured absorber coatings was measured by the AEE INTEC in Gleisdorf [162]. The different absorbers were fitted in identical panels and three panels were simultaneously measured by the quasi-dynamic collector test according to EN 12975-2. For the first series aluminium absorbers with the colours blue and gray were used, as well as a comparison with black coated selective coating. The second series was carried out with copper absorbers, which were coated with the colours green and auburn [Figure 6.5-5]. The efficiency curve obtained from the measurements of the aluminium absorber with the blue coating shows an almost similar performance as those of the absorber with the black selective coating. At low temperature differences, the blue absorption is slightly lower, while coming at the higher temperature differences, the selectivity of the blue coating the thermal efficiency of the blue coating is slightly higher. The conversion factor of the gray absorber is about 16 % lower than that of black absorbers. Figure 6.5-6 summarizes the results for the measured absorber and glass combinations.

The development of selective colour coatings for the absorber is an essential step to bring visually attractive systems on the market.

The new building sector as well as renovation projects can be seen as fields of application for coloured thermal collectors. The development of absorber coatings which are close to the thermal performance of black selective absorbers will be an objective for the next years. Figure 6.5-8 shows a successful example for the integration of blue collector

Figure 6.5-7
Mounting of integrated solar collectors on the roof of an attic conversion in Graz, Copyright: Eduard Wasserfaller

Figure 6.5-8
south façade of an apartment building with 14 flats in Mooserkreuz / Austria. Copyright: Austria Solar [163]

panels in a façade.

Additionally to a bigger variety of colours, increased options for collector shapes would help to increase the acceptance among architects. Rectangular panels in many different aspect ratios are already available. Not rectangular polygonal shapes are still expensive custom-made products in which the not rectangular parts are mainly constructed without absorbers.

6.5.3 Heat storage

One key component of a solar plant or a solar combisystem respectively is the thermal energy store (TES). The heat store has to fulfil the following tasks:

- Deliver sufficient energy to the heat sink
- Decoupling of mass flows of heat sources and heat sinks
- Store heat from an unsteady heat source (like solar) from times where excess heat is available to times when too little or no heat is available
- Extend the running times for auxiliary heating devices in order to increase their efficiency and decrease emissions
- Allow a reduction in heating capacity of auxiliary heating devices
- Store heat at the appropriate temperature levels without mixing in order to avoid exergy losses (stratification)

Today the commonly used type of storage in solar thermal systems is water storage i.e. sensible storage, in which heat is stored by means of a change of temperature of the used storage medium. Several studies have shown that the design of the store in a solar system greatly affects the overall system performance, making it very important to have a good design. Specific testing methods have been developed to judge properties of water stores in solar heating systems like e.g. ENV 12977-3 (CEN, 2001). ([170])

Figure 6.5-9
Example for the emplacement of a standard water store for solar combisystems located in the old town of Graz, Copyright: Eduard Wasserfaller

During the last twenty years research was focused on the enhancement and optimisation of solar water stores, including investigations about the optimum positions and geometries of in- and outlet connections, the enhancement of the thermal stratification, the minimising of heat losses and the reduction of production costs. On the one hand water is unbeaten as a heat storage medium in terms of simplicity and cost, on the other hand the required storage volume in order to achieve for example a solar fraction of 100 % is very large.

Advanced, compact thermal energy storage technologies are therefore considered to be of key importance on the way to a strongly increased use of solar thermal energy. Advanced technologies for storage of thermal energy can be divided into latent heat storage, sorption heat storage and thermo chemical storage. In this sequence the first

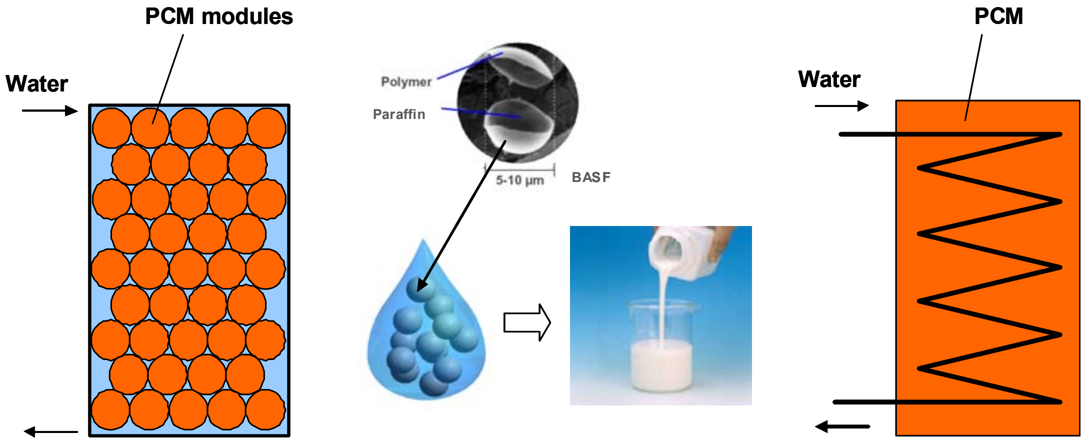


Figure 6.5-10
Different approaches of the integration of PCMs into a storage system (from left to right: macro-encapsulation, micro-encapsulation, bulk PCM tank with immersed heat exchanger), image source: [172]

technology has the broadest application and less potential for improvement, while the last has the highest potential but is still in an early research stage. In Austria several research projects were focused on advanced thermal energy storage techniques during the last years. These activities were among others carried out within the framework of IEA SHC Task 32 "Advanced storage concepts for solar and low energy buildings" [177].

Latent heat storage with Phase Change Materials (PCM)

The storage capacity of Phase Change Materials is not only based on a temperature change but primarily on the latent heat of a phase change – mostly between solid and liquid – of the storage medium. Different possibilities of the integration of PCMs into a thermal energy store have been studied within the projects [187] and [181]. PCMs encapsulated into modules (macro-encapsulation) can be integrated into a standard water tank, in order to increase the storage capacity. As PCM materials typically have a relatively low thermal conductivity, either the size of the modules has to be chosen in an appropriate way (depending on the necessary charge/discharge power) or the conductivity has to be enhanced by adding a material with a high conductivity (see Figure 6.5-11).

Micro-encapsulated PCMs can be mixed with water, which results in a pumpable suspension, called a PCM-slurry. This fluid can be used as a heat store and a heat transport medium. The microcapsules have a size of only 5-20 micrometers, therefore the low thermal conductivity of the PCM material is no more a problem. However, due to the microcapsules, which are used with mass fractions up to 50 %, the viscosity of the fluid increases and therefore the heat transfer properties decrease and the energy demand for pumping increases compared to water.

A PCM can also be directly integrated into a tank, which is charged and discharged via a suitable heat exchanger. This approach has the advantage of a higher possible PCM volume fraction compared to a solution with macro-encapsulation. On the other hand the used heat exchanger has to fulfil certain requirements in order to ensure an appropriate charging and discharging of the tank [172]. In [187] and [181] dynamic system simulations of a solar combisystem with different configurations concerning the size of the collector field and the size and kind of the heat store (water and PCM) were carried out.

The results showed, that the used PCMs offer an advantage in form of increased solar gains, especially for high solar fractions, but that this advantage is too low in order to justify the increased costs of the material and the store.

Sorption heat storage

A sorption heat store is in fact a thermo-chemical heat pump, which is operated under vacuum conditions. This allows evaporation at a low temperature level and water vapour transport without the need of a pump or fan. The basic principle is described below and shown in Figure 6.5-10 (according to [173]).

The following working principle of sorption heat storage is as follows:

1) Charging process (desorption, drying of adsorbent): Heat from a high temperature source (solar thermal collectors) is fed into the device, heats the adsorbent and vapour is desorbed from the adsorbent. The desorbed vapour is condensed at a lower temperature level and then pumped out of the container into a separate reservoir. The heat of condensation has to be withdrawn to the environment.

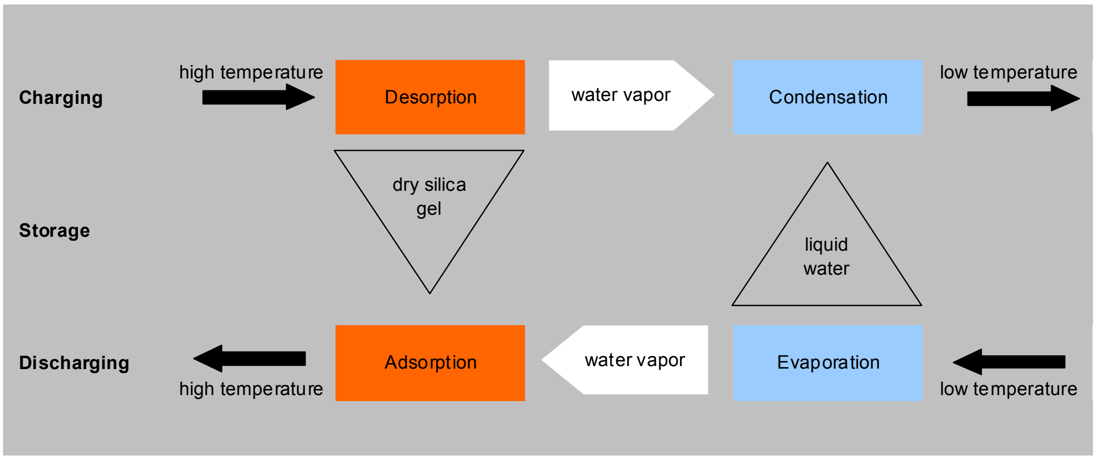


Figure 6.5-11
Working principle of a closed-cycle adsorption heat store, image source: [172]

2) Storage period: The dry adsorbent is separated from the liquid working fluid (the connecting valve is closed). As long as these components stay separate, long-term heat storage without losses is possible if the sensible heat involved is neglected.

3) Discharging process (adsorption of working fluid on adsorbent): Water is pumped into the evaporator where it evaporates taking up heat at a low temperature level. The vapour is adsorbed and releases the adsorption heat at a higher temperature level. This is the useful heat that can be used for space heating.

Development of a prototype

A prototype (see Figure 6.5-12) of a system with the materials combination water/silicagel was developed in the EU Project "MODESTORE - Modular High Energy Density Sorption Storage" [24] by AEE INTEC. This prototype was then tested in a pilot plant installation in the Austrian research project "MODESTORE" [185].

The results showed that the system is working but that the solar fraction, which can be achieved with this type of system, is not higher than achieved with standard water storage of the same volume. The reason is that the storage capacity of the used sorption material, which can be technically used, is much smaller than the theoretical storage density. This is because the temperature lift which can be generated with this material combination is useable only in a quite narrow bandwidth of charging of the silicagel. Therefore a much higher amount of material would be necessary which is feasible neither technically nor economically.

The next step of development would therefore be to develop sorption materials with improved properties, which allow both lower desorption temperatures and a higher temperature lift during discharging.

A large part of the research institutes that work on PCM, sorption and thermo chemical storage has joined the new IEA Task/Annex 42/24 on "Compact Thermal Energy Storage: material development for system integration". The goal of this Task is to find and improve compact thermal energy storage materials through a broad and basic research and development initiative. The Task/Annex will bring together experts from the materials development field and the systems integration field. Presently, more than 41 organisations from 17 countries worldwide collaborate in this Task.

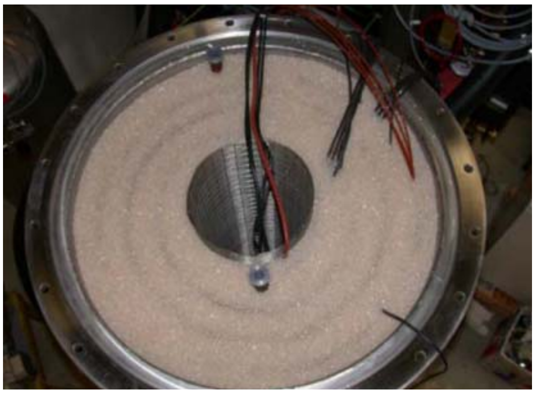


Figure 6.5-12
Prototype storage module developed in (Jaehnig et al., 2006) [173]

6.5.4 Pre fabricated facade elements including solar thermal components

At the moment, most of the renovation projects in Austria reach only the minimum standard of heat protection given in the building code. One main reason for this actual situation is caused by a lack of knowledge and experience with efficient technologies.

Additionally highly efficient construction systems imply an increased level of planning complexity and uncertainties in the building process. The approach to use prefabricated construction elements could relieve many of these problems. Prefabrication allows the assembly of whole facade elements under ideal surrounding conditions in a factory work floor. The use of semi automated machines enables less hours of work and an increased grade of accuracy coupled to a decreased error rate compared to the construction on the building site. This also allows the prefabricated integration of renewable energy systems (solar thermal collectors and photovoltaic panels) and optimised building equipment (heating, cooling and ventilation).

The facade can be transported by truck to the building site, lifted to the right position and be mounted without use of scaffolding, which saves costs. Such prefabricated systems could help to overcome the present obstacles in highly efficient renovation which were mentioned above.

There are several projects currently working on the development of such construction systems. For example the Austrian Project, "Multi-functional Plug & Play Façade" [186] is aimed at the development of an intelligent, multifunctional facade system for use in modular construction methods with the highest possible level of prefabrication for the new build of large scale residential and office buildings and the renovation of existing houses.

Another example can be seen in the IEA project "Prefabricated Systems for Low Energy Renovation of Residential Buildings" which works on prototypes for prefabricated roof systems with integrated HVAC, hot water and solar systems [188]

6.6 Conclusion and outlook

The minimization of the energy consumption in the building stock and the usage of renewable sources of energy becomes more and more the basic principle of innovative property developers. Not only low initial investments are important due to the apartment owners or tenants, also low operating costs, highest possible supply safety and ecological criteria are increasing in their local value.

If these principles are taken seriously into practice, there will be no way around the increased solar thermal usage. Therefore solar thermal use is already standard in the new buildings of many property developers.

In the field of building renovation miscellaneous technical solutions are already available. This paper shows a bunch of different techniques, examples and layers to implement solar thermal systems in the existing building stock. Nevertheless there is still a large necessity for development in the field of system design and component engineering.

The great potential for solar thermal heating systems appears to be very clear in the Austrian building stock. If, in future, this also shall be used, the politics is called to create corresponding general regulations for an amplified realization in this area.

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7 Advanced design solutions – Examples from Denmark and Switzerland

7.1 Examples of design solutions for multi storey housing in Denmark

Frederic Nors

The following study focuses on developing attractive design solutions for energy renovation of existing multi storey housing in Denmark. The study focuses on the type of buildings representing the largest potential seen from the professional building industry's point of view and focuses on combinations of state-of-the–art solutions.

Participants

The project team members are:

Esbensen A/S (proj. man.)

Creo architects A/S

Danish Building Research Institute (SBi)

Rockwool International A/S

Objective

The objective is to develop advanced energy design solutions for renovation of existing housing in Denmark.

7.1.1 Potential building types

The most common type of dwelling in Denmark is detached houses. The total heated area of typical Danish dwellings is approximately 300 million square meters and more than half (51 %) of these houses are detached houses. The second largest type of dwelling is apartment houses. This type of dwellings represents 27 % of the total heated area. Terraced and farm houses only represents 14 % and 8 %, respectively.

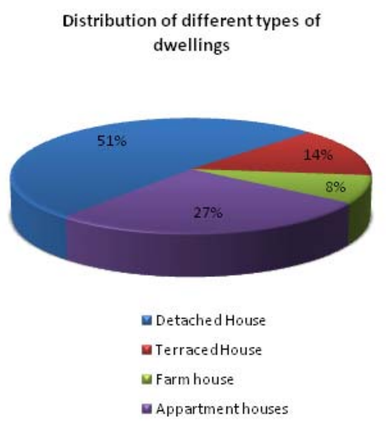

Figure 7.1-1
Distribution of different types of Danish dwellings, 2003.

Most of the detached houses (33 %) were built during the boom in the Danish building industry in the 1960's. In total, about 25 % of all Danish dwellings were constructed in this period and, except for detached houses, this was primarily apartment houses (17 %). Another significant share (25 %) of Danish dwellings is the buildings constructed before 1930. Almost three quarters of all farm houses were constructed in this period but also the majority of apartment houses were

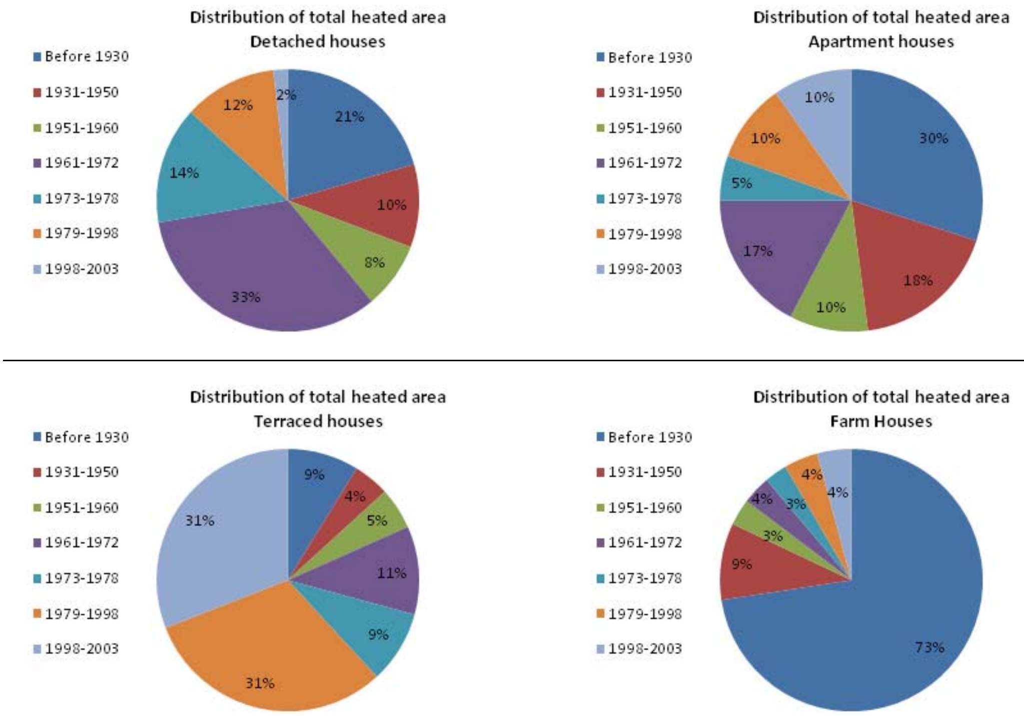

Figure 7.1-2
Traditional types of Danish dwellings distributed on building year

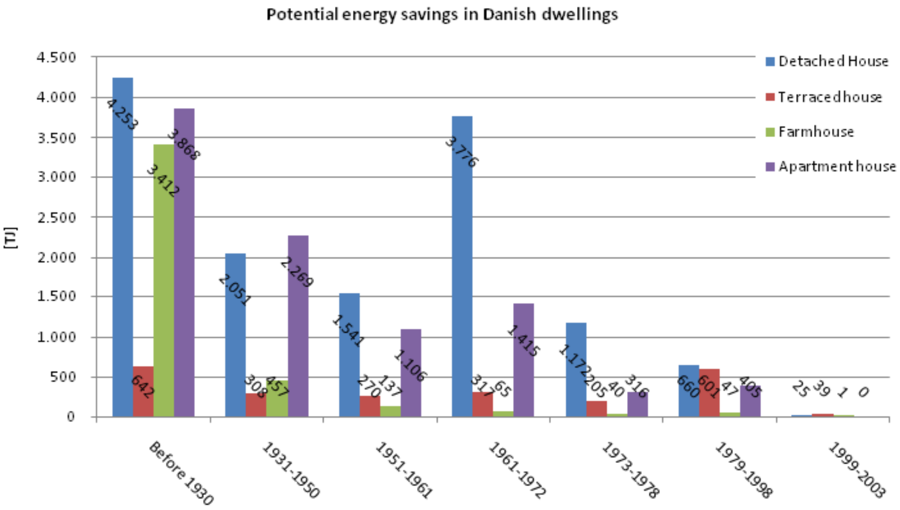

Figure 7.1-3
Distribution of potential energy savings on building year and type of dwelling, 2003.

built before 1930.

Figure 7.1-2 shows the distribution of heated area for different years of construction and building types. The periods are not divided equally but with respect to significant building characteristics induced by introduction of building traditions and regulations by the Danish building code.

Buildings from before 1930 were almost solely built with facades of massive brick work. In the beginning of the 1930's cavity walls were introduced and became by time widely used in the Danish building industry. In the 1950's many experimental and untraditional building styles were built. Cavity walls were filled with insulation in the beginning of the 1950's. In 1961 a new building regulation was introduced and a major boom in the building industry made a general change in the building style. Building elements were industrialized and new building techniques were used. Somewhat 10 years later the building regulations were improved by a new regulative in 1972. A major tightening of the building regulations was made in 1977 (executed in 1979) on the basis of the significant energy crisis in 1973.

Figure 7.1-3 shows the percentage distribution of the potential energy savings in common types of Danish dwellings in 7 building periods. The potential was estimated by the Danish Building Research Institute, SBI[1], on the basis of data from The Danish Authority of Enterprise and Construction (Building and Dwelling Register) and data reported by consultants of The Danish Energy Labelling Scheme[2] (Energimærknings-ordningen).

The figure shows that the largest potential of energy savings is in particular detached houses and especially for the houses build before 1930 and within the building period of 1961-1972. The second largest potential is apartment houses and farm houses from before 1930.

Although the largest potentials for energy savings are within single family houses the probability of energy refurbishments is expected to be higher for apartment houses. The fact that energy refurbishments are more costly to initiate by owners of single family-houses, compared to owners of apartment houses, makes it more cost efficient to renovate apartment houses. In other words, single family housing is not a realistic and attractive market segment for large scale advanced design solutions/designs for renovation of existing housing in Denmark. For that reason, apartment houses encompass the largest realistic potential for energy refurbishments in Denmark.

Apartment houses from before 1930 are mainly constructed in dense populated city areas. In these areas, restrictions to the architectural design and other limitations often complicate external re-insulation or other fundamental changes of the building facade. In consideration of these aspects, the most potential building types for energy refurbishment is apartment houses constructed in the periods 1931-1950 and 1961-1972. Dwellings of this type and

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[1] By og Byg Dokumentation 057: Vurdering af potentialet for varmebesparelser i eksisterende boliger. (2004)

[2] In Denmark, Energy Labelling Schemes have been used as a feasible mechanism to achieving energy savings in existing buildings since 1996.

Table 7.1-1
Apartment houses
Totals and averages of heated and developed areas [m2] and average number of storey distributed on building year year[1].

Building year	Before 193	1931-195	1951-196	1961-197	1973-197	1979-199	1998-200	Total
Total heted area	23.450.35	14.082.05	7.567.891	13.546.25	4.316.888	7.631.531	877.214	71.472.19
Average area	403	623	1.272	1.918	2.155	1.071	1.093	
Total developed area	8.050.120	4.497.274	2.473.632	4.122.888	1.526.696	3.050.991	360.908	24.082.50
Average developed area	165	224	427	596	780	422	423	
Average storey	2.56	2.55	2.77	2.96	2.73	2.47	2.6	

building period have a relatively large potential of energy savings and often fewer limitations with respect to shape of building envelope and architectural expression. Table 7.1-1 shows the totals and the averages of heated and developed areas of apartment houses in Denmark. The table shows that the sum of the developed area in the three periods is approximately 11 million m^2 and involves around 33 thousand buildings. From the table it is also seen that the building height and volume increases in time from the 1930's until early 1970's. A significant drop is seen in the period from 1973-1978 caused by the oil crisis in 1973. Energy savings in apartment houses from later periods have less potential because of better insulation standards.

Data from The Danish Authority of Enterprise and Construction (Building and Dwelling Register) shows that the most common heating system in apartment houses is district heating (69.4 %). 24.6 % of the buildings have central heating and 3.4 % are heated by electricity. The facades of Danish multi-storey houses are in general made of brick work. Danish surveys[1] show that 95.1 % where constructed with a face wall of bricks. Building style and building materials depends on the building period.

7.1.2 Typical constructions for apartment houses 1931 – 1950

Multi storey buildings in Denmark from the period 1930's and 1950's were constructed by typical building components and building methods. Inspiration and illustrations of the following typical constructions are from the Danish building research institute, "SBI-Anvisning 221: Efterisolering af etageboliger", 2008 and Dansk Byggeskik[3].

External walls

Typical façade walls of apartment houses from 1930 to 1950 were made of massive brick work and cavity brick walls in upper floors. The width of the cavity was normally 70 or 130 mm and united by brick work in a distance of 600 mm or made with metal binders. The inner face of the cavity wall was typically made of molar bricks. The parapet was often made of stone piers in order to reduce weight above windows and to obtain better insulation properties behind the radiator. Only few external walls were constructed in heavy concrete instead of brick work already in the early 1930's.

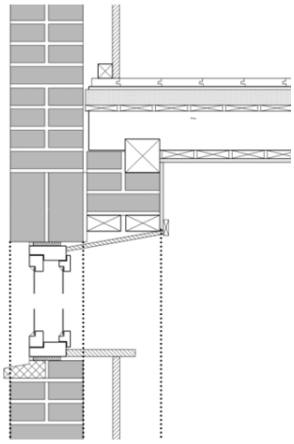

Figure 7.1-4
Position and surrounding constructions of a typical window (the dotted line shows the position of wall between window areas)View from the Southeast

Floors

The buildings were mostly constructed with load bearing external walls and wooden tier of beams, but some buildings were constructed with massive concrete floors instead. Heat conduction between external walls and the concrete floors often led to condensation problems on the inside of the floor because of significant thermal bridges. The risk of condensation were sometimes tried to be reduced by insulating the back wall from the inside in combination with 2-3 cm of cork underneath the floor. These renovations were often carried out later and do not meet today's requirements from the fire authorities.

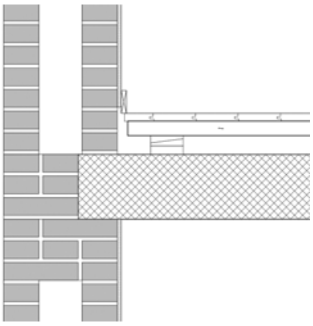

Figure 7.1-5
Concrete floors resting on brick walls often led to condensation problems on the ceiling

Figure 7.1-4 shows a typical design of the joint of a wooden floor and the external wall above a window section. Wooden floors were primarily used in earlier building periods but

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[3] Dansk Byggeskik´s homepage www.danskbyggeskik.dk

also widely used as an alternative to concrete floors in buildings from the 1940's and 1950's. A typical design of the joint of the external wall and a reinforced concrete floor is shown in Figure 7.1-5. Both constructions have significant thermal bridges. The only effective renovation of the thermal bridges is an external re-insulation of the façade.

The window area in this building period is in general larger than previous building periods. Cavity walls were always united by masonry around the window hole and caused a significant thermal bridge. In cavity walls the parapet underneath the window was always massive and often made with a thickness of one brick in order to make room for a radiator on the inside. See Figure 7.1-4.

Windows in Denmark are usually side-hinged windows and opening outwards. Windows from this building period were single glazed windows but in most cases they have been renovated or replaced by newer window designs. Singled pane windows were often renovated by an extra framed pane on the inside. This type of double glazed windows were in many cases again replaced by sealed double glazed windows that had a more slim design but not as good insulation properties as the old type.

Roofs

The roofing of multi-storey buildings is in general made of tile (44.3 %) or fiber-cement (35.9 %)[1]. These two materials are almost entirely used for a sloped roof which offers good space for re–insulation above the roof. In combination with external re-insulation of the façade it is very attractive to reach a solution where the insulation of facades and the roof overlaps. Figure 7.1-6 shows a typical sloped roof construction for this building period.

Basement walls

Basement walls were in general made in concrete without any insulation and with massive brick work 200 mm above ground. Figure 7.1-7 shows a vertical cross sectional cut of a basement wall and basement window. Because the floor is rather close to the basement window the floor cannot be supported by the masonry above the window. In such cases the edge of the concrete floor may be designed as a beam.

Concrete slaps

The concrete slap in this building period is typically made of concrete on a capillary breaking layer. The concrete slap is rarely insulated but may have little insulation in between the joists under the floor or under the concrete. See Figure 7.1-7 and Figure 7.1-8. The concrete slap adjoins the foundation, and the foundation has almost always the same dimension as the external wall. This causes a significant heat loss regardless of whether the external wall is massive or made with a cavity.

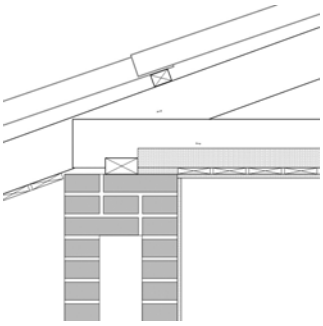

Figure 7.1-6
Typical roof construction

7.1.3 Typical constructions for apartment houses 1961 – 1972

Multi storey housing from the 1960's and 1970's was basically made of precast concrete panels. The heavy external and internal walls were made as load bearing constructions. This allowed a faster building process by use of cranes and a better insulation of the external walls. The concrete elements were designed as sandwich constructions with just enough insulation to meet the requirements. At the time there were no requirements to linear heat losses which have led to significant thermal bridges along edges and connections of the building elements.

Figure 7.1-10 shows an example of significant problems of thermal bridges around connections of concrete elements in a multi-storey building from 1971. In the figure it is seen that the heat fluxes are highest at the supporting edges of the precast concrete building element. The linear heat loss along the concrete floor and the edge of the concrete parapet is calculated to be as high as 1.26 W/mK.

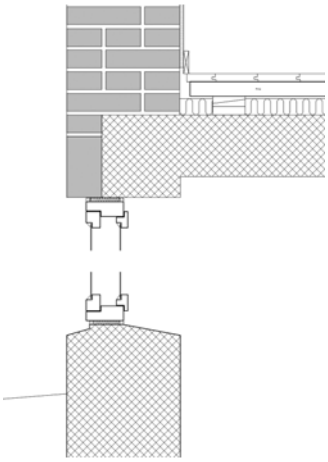

Figure 7.1-7
Vertical cross sectional cut of a basement wall and basement window

External walls and floors

External walls were made of precast concrete sandwich elements. A concrete sandwich element consists in general of a load bearing back wall, insulation and a facing. The back wall is typically 120-180 mm thick, the insulation is often 100 mm mineral wool and the facing is somewhat 80 mm thick and connected to the back wall by a steel hanger at the top. The distance between facing and back wall is ensured by thin metal binders evenly distributed over the entire surface of the concrete element.

Figure 7.1-9a shows the external wall and the joint of the concrete floor. The thickness of the insulation in the wall is often reduced at the edge of the floor. The joint filling between the elements, shown as a dotted line, may be missing, and the tamping between the back

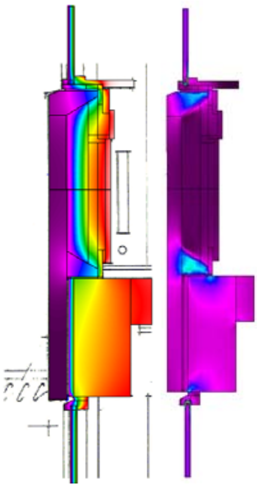

Figure 7.1-8
Isotherms (left) and heat flux (right) through typical façade construction of concrete elements.

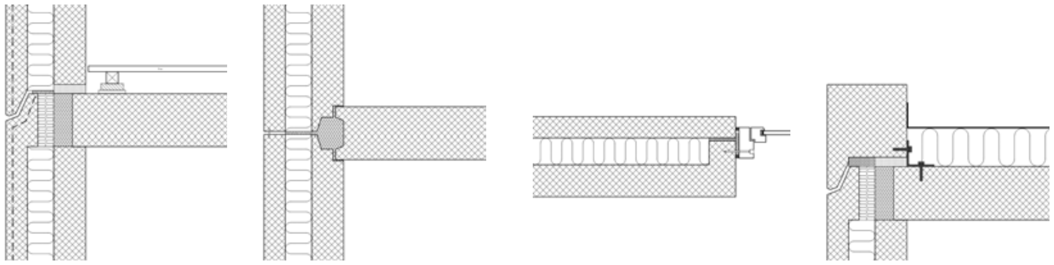

Figure 7.1-9
(from left)

Vertical cross sectional cut of joint of floor and external wall.

Horizontal cross sectional cut of joint of transversal wall and external wall

Horizontal cross sectional cut of Window and external wall.

Typical roofing with bad insulation properties Typical roofing with bad insulation properties

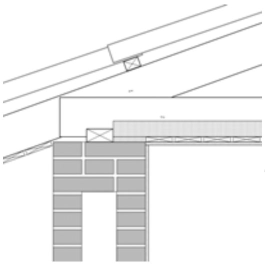

Figure 7.1-10
Typical roof construction

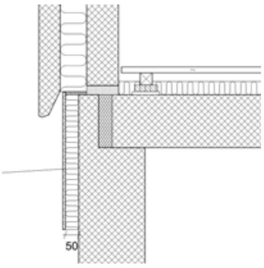

Figure 7.1-11
Uninsulated basement

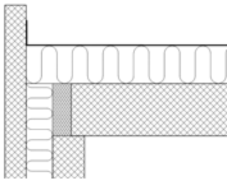

Figure 7.1-12
Typical roofing with good insulation properties

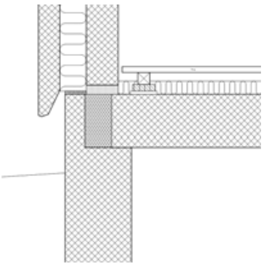

Figure 7.1-13
Outside insulation of basement

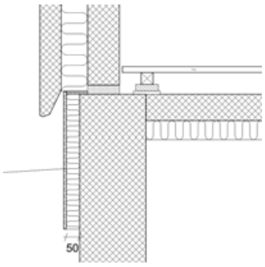

Figure 7.1-14
Outside insulation of ground floor

wall and concrete floor may be destroyed and leaking.

Figure 7.1-9b shows a horizontal cross sectional cut of the joint between external and internal wall. The joint of the facings is sealed by a ribbon and the insulation is protected by a filling. The joint ribbon and the fillings may on most buildings be damaged leading to reduced insulation properties.

Windows

A typical U-value for a double glazed window in a wooden frame is 2.70 W/m^{2}K. In Denmark this corresponds to a typical heat loss of 128 kWh per m^2 window per year. In connection with energy refurbishments the windows will typically be replaced by other windows with better insulation properties.

Figure 7.1-9c shows a horizontal cut of a window frame and the external wall. The insulation of the thermal bridge between the facing and the window frame is typically about 10 mm and causes a significant heat loss. The window frame is often positioned a little outwards compared to the insulation. Problems with damaged and leaking joints often lead to condensation problems and degradation of the wooden window frames.

Roofs

Figure 7.1-9d shows a typical (and bad) roof construction used in multi storey housing from the 60’s and 70’s. The concrete capping and the lack of insulation between the concrete elements create a major thermal bridge. Figure 7.1-12 shows a good construction of the roofing where the insulation of the roof and the façade is connected. The heat conducting capping is avoided and the asphalt roof is attached to the face of the external wall.

Basements

Figure 7.1-11 shows a vertical cross section of typical basement construction. The concrete basement and concrete floor creates a significant thermal bridge but insulation between the joists reduces the heat loss. However, the insulation is not sufficient and in many cases the insulation may be missing due to piping and installations.

Figure 7.1-13 shows a typical improved design. The external insulation reduces the heat loss significantly but still a heat loss through the basement wall and floor will occur.

Concrete slaps

The external back wall will normally be supported by the basement wall or the foundation. The concrete slap is normally made as cast in-situ concrete floor directly in contact with the foundation. The concrete slap may be insulated against the ground by 75 mm insulation (or less) and (rarely) against the foundation by a thin barrier which reduces the thermal bridge. Figure 7.1-14 shows the construction of a ground floor with insulation

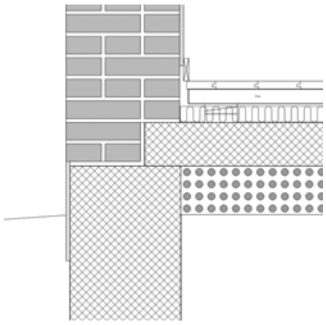

Figure 7.1-15
Typical concrete slap and foundation with insulation in between joists under wooden floor

Table 7.1-2
Specific energy performance data for the apartment building in Assens.

** The building is supplied with district heating*

Energy demand, Assens	**gross area [kWh/m2]**	**Correction factor [-]**	**net area [kWh/m2**
Space heating energy including domestic hot water	187.0	0.83	225.3
Electricity demand (weighted)	1.7	0.83	2.1
Total yearly energy performance	188.7	0.83	227.4

against the ground and external insulation of the foundation.

7.1.4 Potential demonstration projects

The potential of energy savings is exemplified in two specific cases where the design and concept is described for two multi storey housings that are typical and representative for each of the two building periods. The following describes the existing design and energy performance which is used as a reference for the potential of energy saving initiatives.

7.1.5 Apartment building from 1930-1950

The apartment building in Assens is a representative building of Danish building design and technique used in the period 1930-1950. The building is a three storey building constructed in 1949. The building has a 45 degree sloped tile roof with dormer windows and holds 18 apartments including 6 apartments in an attic. The total heated floor area is 1.258 m^2 corresponding to 1.100 m^2 net area. Under the entire ground floor is an unheated basement. The house has south-east / north-west facing facades and no windows in the end walls.

Building services

The space heating and the domestic hot water are supplied by district heating. The heat exchanger capacity for the district heating is 250 kW. The domestic hot water is circulated in a main loop under the ceiling in the unheated basement. The house is equipped with radiators and a waterborne two string heating system. Set point for supply is 70 °C and return is 40 °C. All apartments have natural exhaust air shafts in bathrooms and kitchens. The air change is assumed to be 0.5 $l/s \cdot m^2$ in the winter and higher in the summer (0.9 $l/s \cdot m^2$) due to opening of doors and windows.

Figure 7.1-16
Existing façade of apartment house in Assens (1930 – 1950).

Energy performance

The calculated total energy performance is 188.7 kWh/m^2 (gross area) and includes a yearly electricity demand of 0.7 kWh/m^2. In accordance with the Danish building legislation, electricity is weighted by a factor 2.5 and specific energy performance is based on gross area including inner and outer walls. The specific energy performance data for the apartment building in Assens are shown in the table below and corrected to the IEA SHC Task 37 term (net area). The correction factors are found specifically for Assens as the relation between the external building floor area and the internal floor area.

Figure 7.1-17
Existing design of apartment house in Gellerup (1961 – 1972)

Table 7.1-3
Specific energy performance data for the apartment building in Gellerup.

** The building is supplied with district heating*

Energy demand, Gellerup	ross area [kWh/m2]	Correction factor [-]	net area [kWh/m2]
Space heating energy including domestic hot water	91.9	0.88	104.4
Electricity demand (weighted)	10.0	0.88	11.4
Total yearly energy performance	101.9	0.88	115.8

The domestic hot water demand is assumed to be 250 l/m^2 per year, which is the standard demand used for Danish dwellings if the actual hot water demand is unknown. The energy demand used for heating of domestic hot water is 18.4 kWhrs/m^2 and corresponds to 8.1 % of the total yearly energy demand.

7.1.6 Apartment building from 1961 – 1972

The apartment house in Gellerup is part of a series of buildings that were built in the period 1968 – 1972. The buildings are typical buildings for its time and are very representative for the building period 1961 – 1972. Around 6.000 inhabitants are accommodated in 1.776 apartments of the same type in the area.

The apartment houses in Gellerup are 8 storey buildings constructed in pre-cast concrete elements. The elements are sandwich constructions made of a total of 150 mm reinforced concrete with 100 mm insulation in the middle. The building has a flat roof and an unheated basement. The thermal heat capacity of the heavy building is 160 Wh/K·m².

One building contains 120 apartments of approximately 90 m2. The total heated area is 10,937 m2 (gross area). Each apartment has its own terrace and windows are oriented East / West. There are no windows in the south/north facing end walls.

Building services

The space heating and the domestic hot water are supplied by district heating. The heat exchanger capacity for the district heating is 1,000 kW. The domestic hot water is circulated in a 200 m main loop under the ceiling in the unheated basement. Hot water is distributed vertically in riser pipes in central technique shafts. The house is equipped with radiators and a waterborne two string heating system. Set point temperature for supply is 70 °C and return is 40 °C. All apartments have mechanical exhaust ventilation in the bathrooms and in the kitchens. The air change is assumed to be constantly at 0.43 l/s·m² both in winter and summer. However, too high temperatures in summer are prevented by an increased air change as occupants are expected to open the windows.

Energy performance

The calculated total energy performance is 101.9 kWh/m^2 (gross area) and includes a yearly electricity demand of 4.0 kWh/m^2. In accordance with the Danish building legislation, electricity is weighted by a factor 2.5 and specific energy performance is based on gross area including inner and outer walls. The specific energy performance data for the apartment building in Gellerup are shown in the table below and corrected to the IEA SHC Task 37 term (net area). The correction factors are found specifically for Gellerup as the relation between the external building floor area and the internal floor area.

The domestic hot water demand is assumed to be the same as the standard demand used for Danish dwellings of 250 l/m^2 per year. The energy demand used for heating of domestic hot water is 15.4 kWh/m^2 and corresponds to 12.6 % of the total yearly energy demand.

Table 7.1-4
Energy frames according to the Danish building regulations applicable for dwellings

**A is the heated area including internal and external walls.*

Definition	Energy frame (gross area)* [kWh/m2]
Present energy frame	(70+2200/A)
Low Energy class 2	(50+1600/A)
Low Energy class 1	(35+1100/A)

7.1.7 Target

According to the Danish building regulation, new buildings or building refurbishments concerning more than 25 % of the building envelope (or more than 25 % of the site value), must accommodate the present energy frame. Table 7.1-4 shows the present energy frame and the official definitions of low energy class 1 and low energy class 2 applicable for dwellings**4**.

The aim of the building refurbishment in this project is to reduce the energy demand to be within the energy frame of low energy class 1. An energy performance better than 35.9 kWh/m^2 is set as the target for the apartment building in Assens. For the larger apartment building in Gellerup the target is to reduce the energy demand to less than 35.1 kWh/m^2. This energy demand includes heat and electricity for space heating, heating of domestic hot water and electricity use for the ventilation system and pumps. Electricity demands for lighting and other electronics are not included in the energy frame for housing in Denmark.

The target energy frames (low energy class 1) translated into the IEA SHC Task 37 term (net area) is shown for Assens and Gellerup in Table 7.1-5.

7.1.8 Basic design solutions

To obtain satisfactory energy conservation properties and a good indoor climate the building envelope must be reinsulated from the outside. This method is the only realistic and cost-effective way to avoid the major thermal bridges in the building but will inevitable change the architectural design of the building. In the following basic design solutions and more advanced design solutions are described for the two demonstration projects. The primary energy demand was calculated by the Danish computer program Be06 which is a program that is widely used as a legal documentation when clients must document that a building complies with the present energy frame.

As the design solutions were developed to be applicable for basically all buildings of the described type and building period, the energy demand was calculated for the buildings orientated towards east, south, west and north for each design and concept. As the program includes the efficiency of the heat supply system in the calculation of the total energy demand it was necessary to make the same calculations for houses outside areas with district heating. These houses were assumed to have a gas boiler installed in the building instead of a heat exchanger used for houses in an area with district heating. The results generally showed a 3-5 % higher energy demand when a gas boiler was installed. Since the difference was minor and very consistent only results from calculations for district heating are included in this report.

Building	Target energy frame [kWh/m2] (low energy class 1)	Target nergy frame [kWh/m2] (corrected to net area)
Assens	35.9	43.3
Gellerup	35.1	39.9

Table 7.1-5
Target energy frames according to the Danish building regulations and international standards

7.1.9 Basic design solutions for demonstration project in Assens

The external insulation of the building envelope makes it possible to transform the appearance of the apartment house to a more contemporary building design. See Figure

Figure 7.1-18
Figure 21: Visualizations and basic design principles of the façades

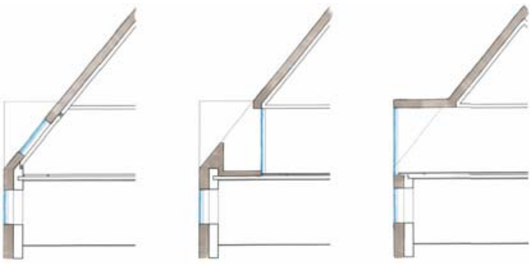

Figure 7.1-19
Design sketches of insulation principles for sky-light and dormer windows.

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[4] Energy demand for lightning is not included in the energy frame for this building category.

7.1-18. The facades of the new building design are re-extended to include the dormer windows in sections in order to reduce the heat transmission area of the building. In the sections where the facades are not extended, the dormer windows are redesigned and changed to roof top skylight windows. Figure 7.1-19 shows the sketches of the future basic roof/facade-construction.

The sketches show the principles and the placement of the external re-insulation. The window area is increased by 75 % but the total transmission area is in total reduced by 14 %. The walls in the dormer window sections are insulated with 400 mm mineral wool reducing the U-value from 0.95 to 0.12 W/m2K.

Facades and end walls were re-insulated by 220 mm external insulation (lambda 0,037) reducing the U-value by almost a factor 10. The basement walls are externally insulated with 125 mm insulation to minimize the temperature gradient between the basement and the ground floor. The floor between the unheated basement and the ground floor was insulated by 100 mm granulated mineral wool in the construction and 100 mm mineral wool on the outside of the construction (basement ceiling). The ceiling was re-insulated by 275 mm mineral wool reducing the U-value from 0.2 to 0.09 W/m^{2}K.

All windows were replaced by more energy effective windows having a U-value of 1.0 W/m^{2}K and a g-value of 0.55. The frame factor was unchanged at 0.8. Some of the dormer windows were changed into skylight windows. The total window area was increased from 195.8 m^2 to 343.3 m^2. This included establishment of 8 m^2 windows in both end walls.

Table 7.1-6
Table 6: Existing and future insulation properties for the basic building design in Assens.

Construction	Existing U-value [W/m2·K]	Description of future construction	Future U-value [W/m2·K]
Outer walls Between windows	1.45	20 mm render. 220 mm mineral wool. 350 mm cavity wall without insulation (2 x 110 mm bricks with binders).	0.15
Outer walls	1.33	20 mm render. 220 mm mineral wool. 350 mm massive brick wall	0.15
Parapet (radiator niches)	1.05	20 mm render. 220 mm mineral wool. 230 mm massive brickwork.	0.15
End walls	1.47	20 mm render. 220 mm mineral wool. 300 mm cavity wall with binders	0.16
Basement wall	2.18	125 mm basement wall insulation. 350 mm massive concrete	0.27
Basement wall (below 2 m under terrain)	0.93	125 mm basement wall insulation. 350 mm massive concrete	0.25
Windows	2.70	Double glass pane in wooden frame. Frame area is 20 % of window. g-value reduced from 0.76 to 0.55. New skylight windows with same properties in the roof.	1.00
Roof (ceiling of top floor)	0.20	275 mm mineral wool on existing construction consisting of 125 mm mineral wool in wooden construction, 25 mm formwork and 10 mm render.	0.09
Roofing	1.31	Rain protection, 350 mm mineral wool in wooden construction. 2 x 13 mm gypsum boards.	0.12
Floor between 1st floor and unheated basement	1.06 - 1.51	20 mm parquet, 100 mm mineral wool (granulate) in wooden construction, 50 mm hard wood and pugging. 25 mm formwork and 100 mm mineral wool. 13 mm gypsum boards.	0.19
Concrete slap	0.41	120 mm concrete on 150 mm capillary break layer	0.41
Dormer windows (wall-construction)	0.95	5 mm zinc, 22 mm ply wood, 400 mm mineral wool in wooden construction and 26 mm gypsum boards.	0.12
Dormer windows (Roof)	0.95	5 mm zinc rain protection with 22 mm chipboard, 350 mm mineral wool in wooden construction and 2 x 13 mm gypsum boards.	0.13

A balanced mechanical ventilation system was installed in the building to ensure a good indoor environment and to exploit the opportunities of heat recovery. The ventilation system supplies the apartments with fresh air by 0.30 l/sm^2, corresponding to an air change of 0.5 h^{-1}. Natural ventilation caused by infiltration is assumed to be 0.13 l/sm^2 (0.19 h^{-1}) in the winter and up to 2 h^{-1} during summer, as a result of opening of windows. The ventilation system has a counter flow heat recovery unit with an efficiency of 0.85 %. The specific fan power demand is 2,000 J/m^3.

The linear heat loss is reduced from 0.10 to 0.03 W/mK around windows and external walls. Around the future skylight windows a linear heat loss of 0.10 W/mK is added. .Around the perimeter the linear heat loss of 0.40 W/mK is assumed to be negligible after the external re-insulation.

7.1.10 Basic design solutions for demonstration project in Gellerup

As part of the external re-insulation of the building façades the existing terraces will be utilized and converted from an unheated area to a heated area. The total heated area of the building is hereby increased from 10,937 m^2 to 12,271 m^2. The change of the façade also lead to a complete replacement of all existing windows that will be moved further out in the façade and aligned with the new external insulation layer. The window area is increased to 70 % in the south façade and reduced to 30 % in the north façade.

The roof is insulated externally by 275 mm mineral wool (+ 125 mm existing) and ensured to reach and unite the insulation of the façades and end walls. This is done in order to avoid an extra heat loss due to thermal bridges in the rim of the concrete roof. See Figure 7.1-20. The floor between the unheated basement and ground floor is insulated underneath by 100 mm mineral wool. In order to reduce the heat loss caused by thermal bridges from the unheated basement, the upper part of the internal walls in the basement, adjoining the concrete floor, should be insulated. The basement walls are externally insulated with 125 mm insulation to minimize the temperature gradient between the basement and the ground floor.

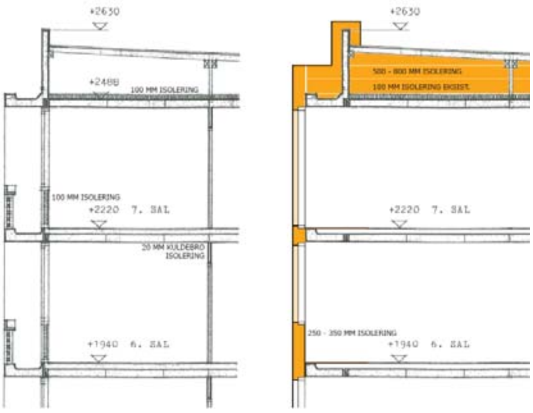


Figure 7.1-20
Design sketches of insulation principles for roof and façades.

Linear heat losses for the existing constructions were assumed to be 0.40 W/mK along the perimeter and 0.03 W/mK around windows and outer walls and. The linear heat

Table 7.1-7
Existing and future insulation properties for the basic building design in Gellerup

Construction	Existing U-value [W/m2·K]	Description of future construction	Future U-value [W/m2·K]
Outer walls	0.37	Light weight façade elements with 300 mm insulation.	0,15
Parapet	0.35	Light weight façade elements with 300 mm insulation.	0.15
End walls	0.37	Rain screen, 220 mm insulation, concrete panel consisting of 150 mm reinforced concrete and 100 mm insulation.	0.13
Windows	2.70	Triple glazed windows. G-value of 0.55. Frame factor: 0.8. Total area of 3,080 m2 reduced to 2,415 m2. Window area facing south was increased to 70 % of the façade area and the window area facing north was reduced to 30 % of the façade area. 32 m2 windows in both end walls.	1.00
Roof	0.37	Asphalt roofing, an average of 640 mm mineral wool blown into existing attic, 100 mm polystyrene and 180 mm concrete.	0.05
Floor between ground floor and unheated basement	0.38	20 mm parquet flooring on joists. Concrete panel of 180 mm reinforced concrete and 240 mm mineral wool.	0.18
Basement walls	1.17	125 mm external insulation and 200 mm concrete.	0.24
Basement flooring	0.41	180 mm concrete on 150 mm capillary breaking layer.	0.41

losses are assumed to be negligible after the renovation. The energy demand used for domestic hot water is 13.8 W/m^2 (40 %).

To ensure a good indoor air quality, a balanced mechanical ventilation system with heat recovery is installed. A counter flow heat recovery unit with the desired capacities is available with an efficiency of 85 %. Because of space limitations the duct work is not optimized for a low pressure loss and the specific fan power (SFP) is not expected to be lower than 2.0 kJ/m^3. The ventilation rate is set to 0.30 l/sm^2 corresponding to an air change of 0.5 h^{-1}. The infiltration is expected to be unchanged at 0.13 l/sm^2, though the renovation of the entire building envelope may lead to a reduced heat loss caused by infiltration. The properties of the building constructions are listed in Table 7.1-6.

7.1.11 Energy performance for basic design solutions

The basic energy refurbishments in the two demonstration projects representing typical houses in the two building periods resulted in major energy savings. The energy demand for the apartment house in Assens was reduced from 188 kWh/m^2 to 45 kWh/m^2 (gross area) corresponding to 226 kWh/m^2 to 54 kWh/m^2 (net area). A reduction of 76 %! If the building was supplied by a gas boiler in the building instead of district heating (DH) the reduction would be a little higher (78 %).

In Figure 7.1-21 it is seen that the electricity demand is extremely low in the reference building but increased in the basic design solution. In the reference building the power demand is only for pumping and distribution of hot water, since there is no electricity use for mechanical ventilation in the building. In the basic design a mechanical ventilation system is introduced which reduces the heating demand significantly.

Figure 7.1-22 shows that the energy demand for the apartment house in Gellerup (DH) was reduced from 102 kWh/m^2 to 32 kWh/m^2 (gross area) corresponding to 116 kWh/m^2 and 38 kWh/m^2 (net area). A reduction of 67 %! If the heating was supplied by a gas boiler in the building instead of district heating (DH) the reduction would be a little higher (70 %).

7.1.12 Advanced design solutions

The target for the apartment building in Assens is an energy demand of less than 35.9 kWh/m^2 which corresponds to the Low Energy Class 1 with respect to the Danish building regulations. This target is not reached with the basic concept only. The following section describes several advanced design solutions for reducing the energy demand further by more effective technical building service systems. The advanced design solutions will not affect the building envelope or the design of the building construction compared to the basic design solutions.

The target for the apartment building in Gellerup is an energy demand of less than 35.1 kWh/m^2. This target is reached by the basic design solutions and the building will be within Low Energy Class 1. In order to reach even lower energy demands, the advanced design solutions are analyzed for the multi storey house in Gellerup too.

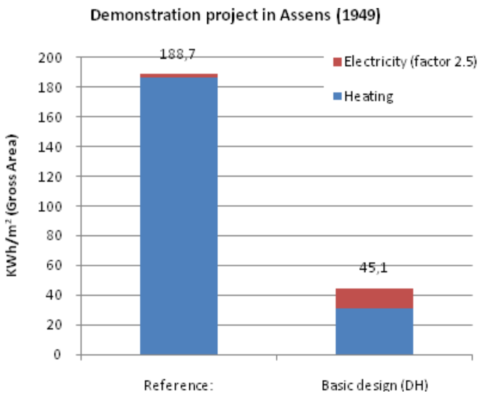


Figure 7.1-21
Energy demand for the apartment house in Assens

7.1.13 Advanced design solutions for buildings from 1930-1950

The effects of several advanced design solutions for the apartment house in Assens were analyzed. The advanced design solutions are additional interventions that should be combined with the basic design solutions. The following interventions were analyzed:

- Low pressure loss in ventilation system
- Demand controlled balanced ventilation
- Demand controlled exhaust ventilation
- Ground-coupled heat pump
- Solar heating systems
- Extremely air tight building envelope
- Combinations of above

Low pressure loss in ventilation system

The interior and internal design and dimensions may in some cases allow space enough to install a more efficient duct work for the ventilation system. In such cases the reduced pressure loss in the duct system may lead to a reduced energy demand for the distribution of air. The specific fan power (SFP) was assumed to be reduced from 2.0 to 1.5 kJ/m^3 (25 %).

Demand controlled balanced ventilation

In order to reduce the electricity use and the heat loss due to ventilation, a demand controlled balanced ventilation system could be installed. By installation of a demand controlled ventilation system, controlled by CO$_2$ concentrations or relative air humidity, the average ventilation rate may be reduced from 0.30 l/sm^2 to 0.18 l/sm^2 (40 % reduction). The specific fan power, SFP, is set to 2.0 kJ/m^3 as no changes of duct work and heat recovery is considered.

Demand controlled exhaust ventilation

The reduced amount of recovered heat may result in a higher pay back time for a balanced ventilation system and the effect of using a more simple demand controlled exhaust ventilation system is therefore analyzed. The SFP is set to 1.0 kJ/m^3 as no heat recovery and no ducting for the supply air is necessary. This design solution is relatively inexpensive compared to a solution with a balanced ventilations system.

Ground-coupled heat pump

Ground-coupled heat pumps are also called ground-source heat pumps, earth-coupled heat pumps, and geothermal heat pumps. The heat pumps may be of different designs depending on local conditions. Some systems may use horizontal trenches for the ground coupling and others use a vertical bore hole. The ground-coupled heat pumps are assumed to be of relevance outside areas supplied with district heating. The COP is assumed to be 3.5 for space heating and 3.0 for DHW, though the COP may vary between different systems and depending on set point temperatures. In periods with 50 % load the COP is assumed to be 1.25.

Solar heating systems

Solar heating systems are very attractive in areas without district heating. A solar collector area of 40 m^2 is assumed to be a satisfactory size for a system supplying 18 apartments (2.2 m^2 per apartment). The solar heating system is designed to cover the heating of domestic hot water only and not to be used for space heating. The solar panels were tilted 45 degrees and oriented towards south when possible.

Extremely air tight building envelope

Due to Danish calculation procedures the infiltration is set to 0.18 h^{-1} (0.13 l/sm^2) in buildings of today's standard. The radical changes of the building envelope may reduce the air change rate caused by infiltration. If the renovation of the building envelope is made very air tight the infiltration is expected to be reduced to 0.1 h^{-1} (0.07 l/ sm^2).

Combinations of above

Additional reductions of the energy demand are studied through different combinations of the above possibilities. For all combinations the advanced design solutions are added to the basic design solutions. The combinations analyzed are:

Combination 1:

- Basic design solutions
- Demand controlled ventilation
- Solar heating DHW

Combination 2:

- Basic design solutions
- Demand controlled ventilation
- Solar heating of DHW

Combination 3:

- Basic design solutions
- Demand controlled ventilation
- Solar heating of DHW
- Ground-coupled heat pump

Combination 4:

- Basic design solutions
- Demand controlled ventilation
- Solar heating of DHW
- Ground-coupled heat pump

Combination 5:

- Basic design solutions
- Solar heating of DHW

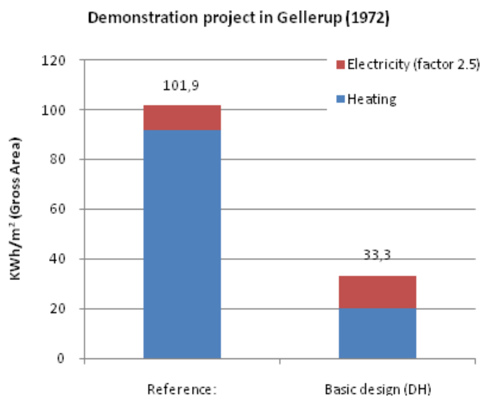


Figure 7.1-22
Energy demand ion for the apartment house in Gellerup

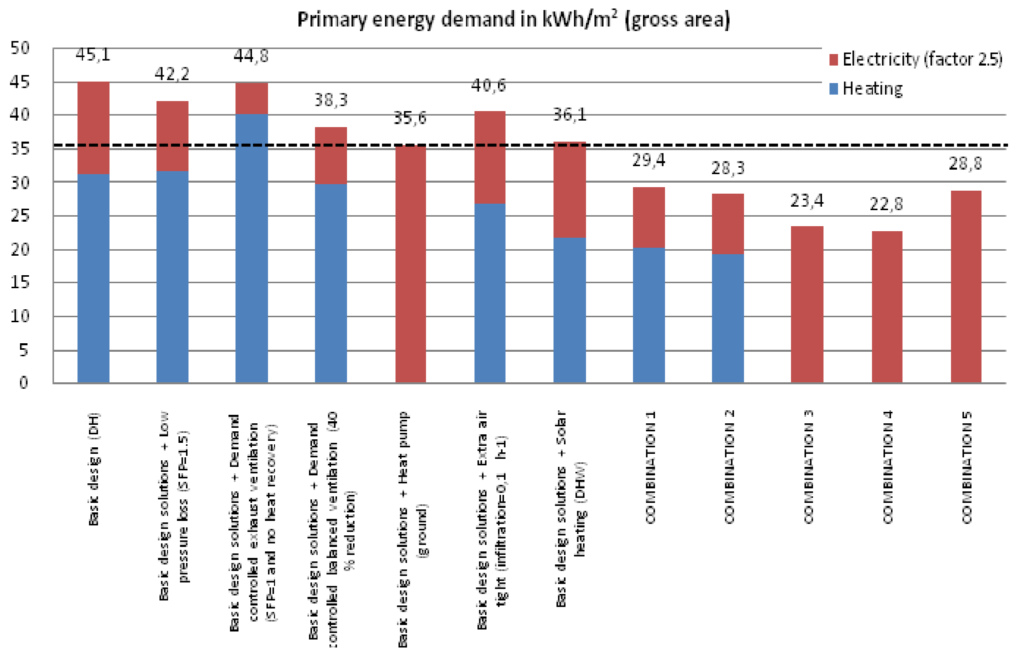


Figure 7.1-23
Primary energy demand in kWh/m2 (gross area) for basic design solutions and advanced design solutions in Assens.

- Ground-coupled heat pump

The primary energy demand for the basic design solutions and different advanced design solutions used in Assens is shown in Figure 7.1-23. Apart from using a ground-coupled heat pump, it is seen that it is not possible to meet the target energy demand of 35.9 kWh/m^2 (gross area) with the basic design solutions and a single concept of energy savings. Combinations of the advanced design solutions will, on the other hand, bring the energy demand far below the target energy demand.

The basic design solutions without windows in the end walls in combination with a solar heating system, a ground-coupled heat pump and a demand controlled ventilation system, will bring down the energy demand to 22.8 kWh/m^2. This corresponds to 27.5 kWh/m^2 (net area) and the primary energy demand is hereby reduced by 88 % compared to the existing energy demand of 227.4 kWh/m^2 (net area). Furthermore, it is 36 % lower than the target of 35.9 kWh/m^2 (low energy class 1).

7.1.14 Advanced design solutions for buildings from 1961-1972

The same advanced design solutions as used in Assens were used for the apartment house in Gellerup. However, some of the advanced design solutions were adjusted or irrelevant for this building type. I.e. the flat roof made it possible to maintain an optimum south facing orientation (with a 45 degree tilt) of the solar heating panels. The area was adjusted to 262.5 m^2 corresponding to 21 panels of 12.5 m^2 (2.2 m^2 per apartment). The ground-coupled heat pumps were not found suitable for the building in Gellerup and windows in the end walls were not part of the basic design solutions. The following advanced design solutions were analyzed:

- Low pressure loss in ventilation system
- Demand controlled balanced ventilation
- Demand controlled exhaust ventilation
- Extra air tight building envelope
- Solar heating systems
- Combinations of above

Combination 1:

- Basic design solutions
- Demand controlled ventilation
- Solar heating of DHW

Combination 2:

- Basic design solutions
- Demand controlled ventilation
- Solar heating of DHW
- Extra air tight building envelope

Combination 3:

- Basic design solutions
- Demand controlled ventilation
- Solar heating of DHW
- Extra air tight building envelope
- Low pressure loss in ventilation system

The primary energy demand for the basic design solutions and different advanced design solutions used in Gellerup is shown in

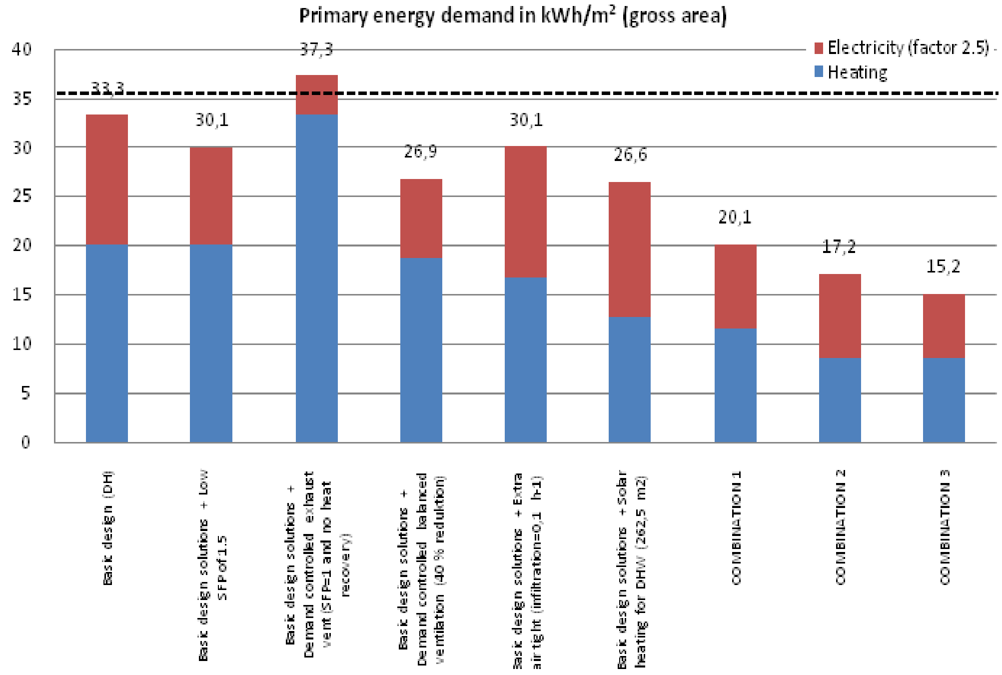


Figure 7.1-24
Energy demand in kWh/m2 (gross area) for basic design solutions and advanced design solutions in Gellerup

Figure 7.1-24. From the figure it is seen how each concept influences the primary energy demand. It is noteworthy that the exhaust ventilation with no heat recovery does not meet the target energy demand of 35.9 kWh/m^2 (gross area). The basic design solutions in combination with an extra air tight building envelope, a solar heating system and a demand controlled ventilation system with a low pressure loss, will bring down the energy demand to 15.2 kWh/m^2 (gross area). This corresponds to 17.3 kWh/m^2 (net area) and the primary energy demand is hereby reduced by 85 % compared to the existing energy demand of 115.8 kWh/m^2 (net area).

7.2 Renovation of Historic, Protected Buildings in Geneva

Willi Weber, Geneva

7.2.1 Foreword

The objective of SHC task 37 is to "develop a solid knowledge base on how to renovate housings to a very high energy standard and to develop strategies that support the market penetration of such renovations".

Renovation of existing buildings is the major potential to implement energy saving and reducing energy consumption (new buildings represent only 1 to 2% of the built environment per year). But in order to achieve high energy standards it implies heavy renovation with important interventions on the envelope.

But for protected buildings of architectural quality and historical importance (that represent, for example, over 30% of Geneva's built environment) heavy renovations are difficult and often questionable. In case of renovation, contradictory requirements occur between patrimonial commissions (concerned with the preservation of the architectural heritage) and energy offices (with the mission to apply the law and drastically lower energy demand).

The purpose of this project is to help architects, energy and patrimonial commissions to achieve thermal renovation of buildings with architectural and historical value by:

- Showing exemplary achievements.
- Describing technical solutions and building details of a selected range of projects.
- Exploring the limits of possible thermal improvements for various kinds of buildings.

7.2.2 Protected buildings of historical value in Switzerland

In the frame of the Federal law of town and country planning assessing the necessity to protect zones and objects, the legislation is up to each canton that has own law on monuments, nature and sites' protection.

Example of Geneva

The example of Geneva is relevant for Switzerland with all kinds of protected constructions including also modern buildings. Protection includes:

Protected zones

There are sites regarded as remarkable and worth to be protected such as villages, old town and blocks of buildings.

Classified Objects

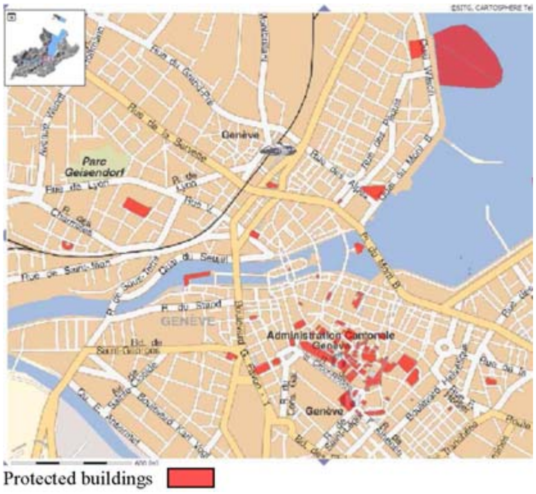


Figure 7.2-1
Portected Buildings in Geneva

It concerns more than 300 buildings. The classification of buildings worth to be protected constitutes is the oldest safeguard measure for Geneva, that came into effect simultaneously with the first law of protection of monuments and sites in 1920.

Originally the classification especially aimed at churches, castles, urban and country houses, fountains and also archaeological sites. Today the protection also includes industrial heritage, as well as built objects from the 19th and 20th and centuries.

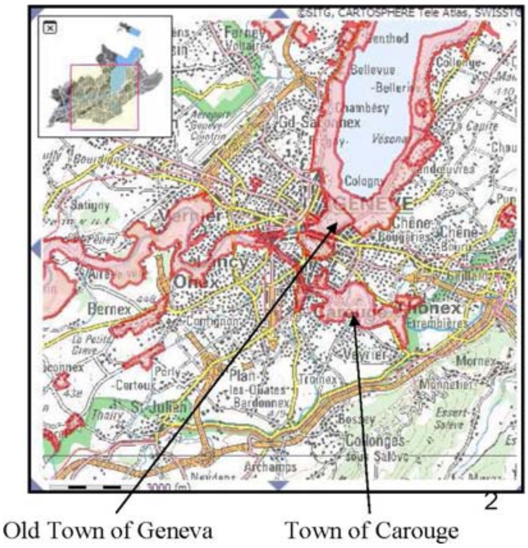


Figure 7.2-2
Portected Zones in Geneva

Inventory of buildings of historical value

For many years, the authorities in charge of the protection of the architectural heritage in Switzerland and abroad have established an inventory, i.e. a repertory of the buildings and objects recognized as being of interest. This repertory undergoes permanent updates. It points out a relatively high number of buildings or interesting objects going back to various periods, including the 19th and 20th centuries.

7.2.3 Typologies for protected buildings

In thermal renovation of protected buildings, the interventions on the walls of the thermal envelop and the windows are delicate and are most of the time limiting factors. If up to this day the glazing has been the subjects of many studies and benefit from a range of technical solutions and available components, it is not the same for the thermal improvement of the walls. The difficulty which inevitably arises is how to integrate insulation in a classified building. Except monolithic walls there are two main solutions:

- Internal insulation, not optimal because of the ruptures of the continuity of the insulation at each concrete slab or partition wall, causing cold bridges;
- External insulation, a solution that ensures the continuity of the insulation and offers optimal insulation, but affects the external appearance of the buildings.

Classify buildings by typology may help to find clever solutions able to be applied for renovation.

Therefore, in this research, we will try to classify the buildings' envelopes in relation with the structure and the position of the insulation.

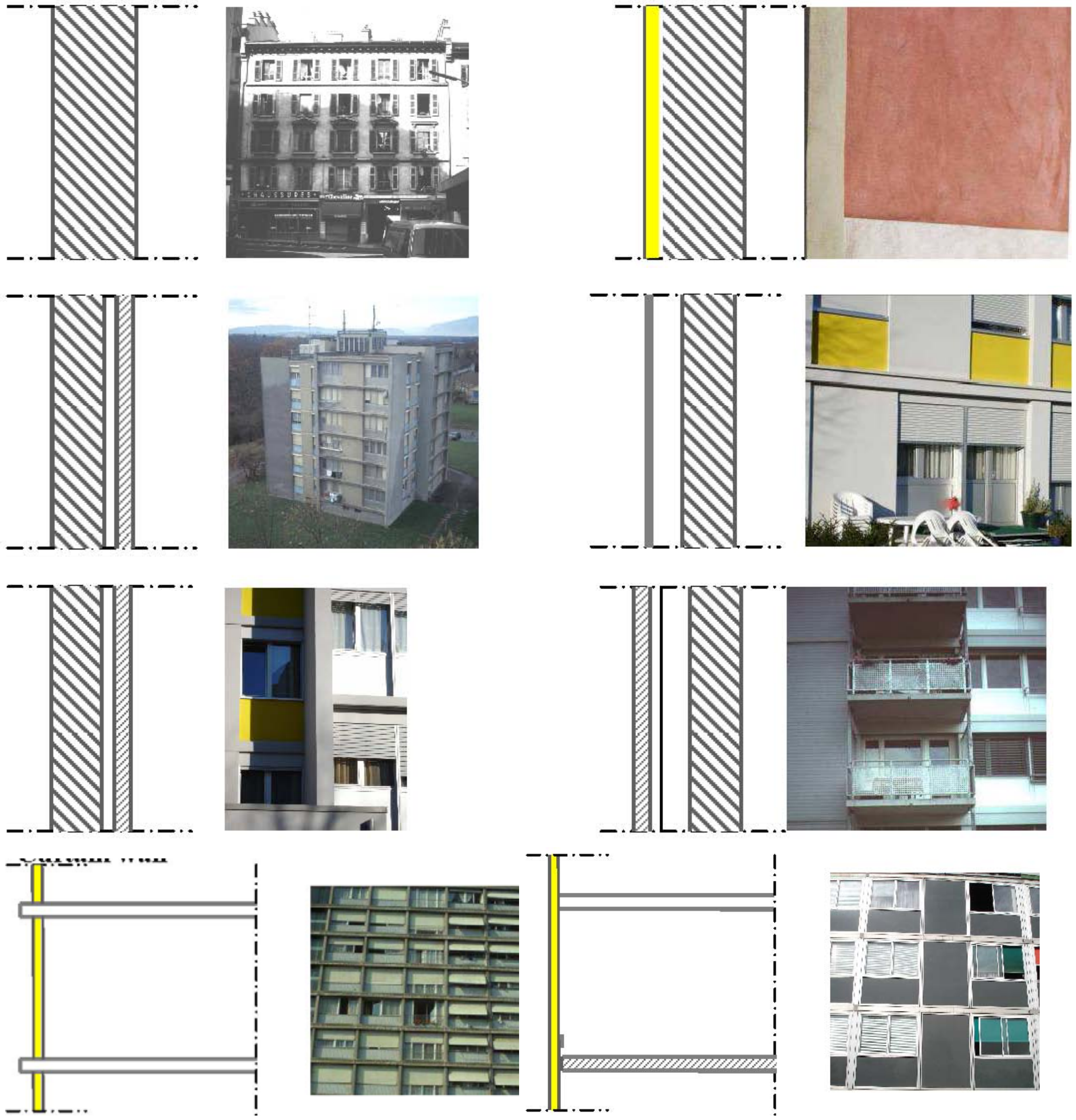


Figure 7.2-3

Monolithic Insulating stucco Interrupted (by floors slabs/walls)

Cavity insulation Stucco over insulation Continuous (over floor slabs)

Interior insulation Cladding over insulation Light façades

Curtain Wall

7.2.4 Typologies of walls

Walls from old buildings are often homogeneous and act at the same time as thermal insulation and structure. In farms and castles the massive stone walls used to be covered with wood to insure a better thermal comfort. In the middle of last century, buildings were insulated with double brick walls. External insulation appeared only during the 80's, with different types of claddings. Light façades or curtain walls have been in use since the 60's as filling between walls and slabs or as a continuous wall covering the façade. See Figure 7.2-3.

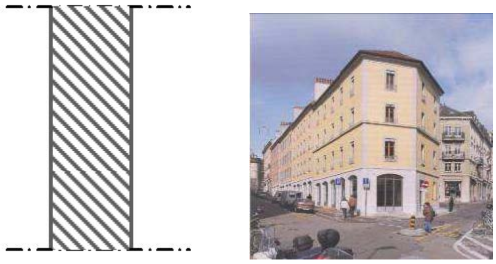
Selection of buildings

A selection of four buildings illustrates this study based on the following criteria:

- Buildings listed for patrimonial value,
- Buildings representing different periods and different types,
- Participation of the CUEPE[1] at some stage of the project (For the City of Lignon and Cayla, participation in the mediation between the Cantonal Office of Monuments and Sites, the Cantonal Service for Energy and the owners).
- Availability of technical data and records of energy consumption.

The number of analysed buildings should be increased in order to be able to have a consistent overview. But already with these four buildings, representing the main typologies, we can make some statements about the lowering of the energy demand for heating in protected buildings and about the limiting factors for insulation:

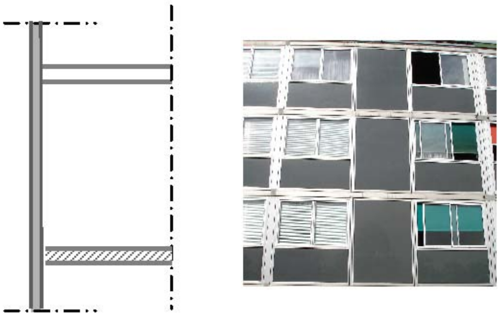
Figure 7.2-4



Type 1:
20, rue des Grottes Building 1870 Renovation 2002

Type 2:
Cayla towers Building 1954 Renovation 2002

Type 3:
Boulevard Carl-Vogt Building 1962 Renovation in preparation



Type4
Cité du Lignon Building 1964-67 Renovation 2010

7.2.5 Conclusion

After careful "renovation", with respect of architectural qualities it was possible to reduce energy demand of the four examples:

- Type 1: 20rue des Grottes, from 272 kWh/m²/year to 117 kWh/m²/year
- Type 2: Cayla towers, from 227 kWh/m²/year to 117 (internal insulation) and 102 kWh/m²/year (external insulation)
- Type 3: Boulevard Carl-Vogt, from160 kWh/m²/year to 74 kWh/m²/year
- Type 4: Le Lignon, from 122 kWh/m²/year to 53 kWh/m²/year (simulation)

We see that even for protected buildings, a careful "renovation", with respect of architectural qualities, is able to reduce drastically the energy consumption without altering the architectural quality of the building.

But lowering energy consumption of protected and historical buildings to the level of the 2000W society, Minergie or Passive is still difficult. Special technical improvements could still lower energy consumption, for example:

- Implementation of the double flux ventilation (in general very difficult and expensive to implement in existing buildings) could lower the energy consumption around 10 to 12 kWh/m²year.
- Vacuum insulation panels would be an adapted solution when by inner construction (40 to 50 % of the space can be saved) [2]. These panels need a careful detailed planning and are not yet commonly used by building contractors.

Innovative or especially effective improvements

For Rue des Grottes:

- The insulating stucco, because of the large surface of the walls, has a important effect on energy consumption and comfort.
- Double-flow ventilation with heat recovery (10% savings) and solar water storage are located on the top floor under the roof with central gas heating (near the solar collector and saving of air ducts).

For Cayla:

- The opportunity to compare energy savings and architectural impact on scale 1/1 with two identical buildings improved with internal and external insulation is quite exceptional.

For the Lignon:

The scale of the building (3700 apartments and today 7000 inhabitants) and the limited types of components of the façade requires a careful analyse and verification with prototypes in order to be able to apply the chosen solution on all the buildings and insure the foreseen energy savings (more than one million litres of oil).

Limiting factors for wall insulation

Buildings with massive masonry :

- Risks of moisture at the head of the beams of the floors.
- Embrasures of windows that limit the thickness of wall insulating rendering and cause thermal bridges.
- Massive stone walls that must remain visible.

The limiting factors of Cayla are:

- The « historical value imperatives » limit the thickness of the external thermal wall insulation in order to maintain the proportions of the different elements constituting the complex architectural expression of the façade.
- Internal insulation is limited by the very small surface of the apartment and can not avoid all the thermal bridges

For Car-Vogt building:

- External insulation changes the look of the building, and thickens architecture details.
- Available space in the balconies is diminished.
- The important proportion of windows (over 30%) makes it more difficult to apply external insulation.

For the Lignon:

This typology avoids the important thermal bridges at the head of walls and slabs. External insulation is quite easy to apply. Limiting factors are:

- Necessity of scaffoldings (15 and 33 floors).
- Need to empty at least a part of the building (no tenant) that implies costs.

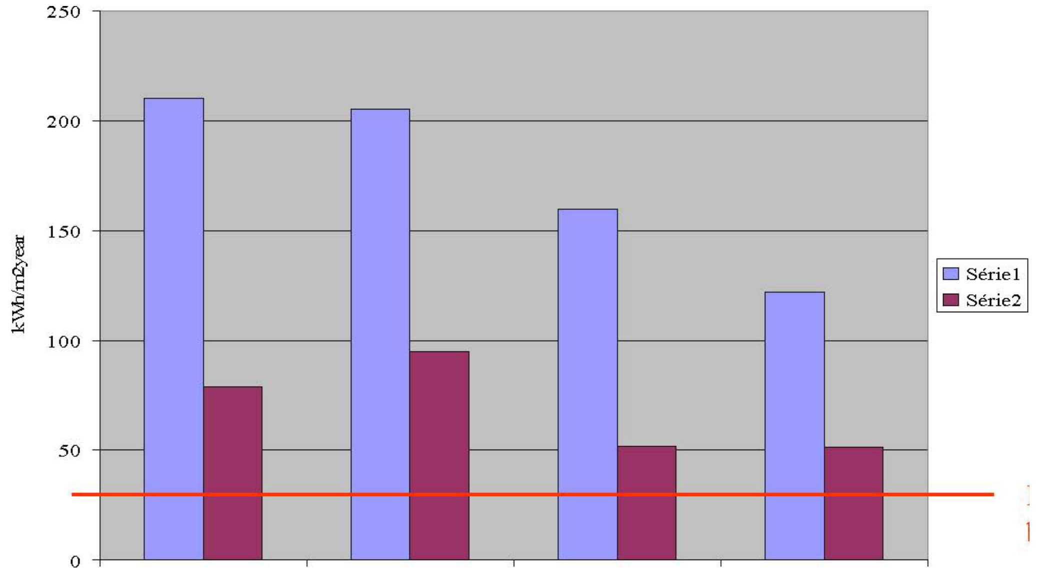


Figure 7.2-5
Energy demand reduction

1 CUEPE, Centre Universitaire d'Etude des Problèmes de l'Energie, University of Geneva

2 Gregor Steinke, Armin Binz, Bausystem mit VIP – Hinterlüftete Fassaden und innendämung, Status Seminar 2008,pp 275-282

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Le Lignon

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8 Performance

8.1 Energy Performance and cross analysis of demonstration buildings

Sebastian Herkel and Florian Kagerer

8.1.1 Background and Methodology

In new buildings the so called "passive house technology" with an energy demand for heating of 15 kWh/m²$_{NFA}$a could be stated as state of the art even though a thorough quality assurance is needed to achieve this goal. An energy supply for these buildings based on locally produced renewable energy in order to achieve net zero energy buildings is shown in various demonstration projects [208].

An analysis of measurements taken for completed renovation concepts provides the basis for further developments of energy efficiency measures and energy supply concepts. This section focuses on the analysis of energy consumption and supply systems in realized projects. For further Analysis on specific aspects see Chapter 4.4 (Ventilation with and without heat recovery) and Chapter 5.1 (Concepts for Net Zero in retrofit).

8.1.2 Projects

Within IEA Task 37 more than 60 buildings from Europe and Canada are documented and analyzed (See Chapter 8.2). Due to the availability of detailed measured data the German subset of buildings was chosen for a more detailed analysis. Table 8.1-2 shows the German buildings documented in this study. Some of the projects presented here were promoted as part of the German Funding Program ENOB, some of them as part of the German Energy Agency's (dena) pilot project "Niedrigenergiehaus im Bestand" ("Renovating for low energy consumption") [209],[210].

A common understanding of energy terminology and areas related to these parameters is a prerequisite for a successful work on an international level. UE indicates energy used in the building, EE indicates end energy at site including distribution and storage losses e.g.; PE indicates primary energy using national conversion factors for heat and electricity. The following definitions were used for area related energy characteristics: The heated net floor area NFA for the measurement analysis and A_{use} as an artificial area derived from the heated gross volume $A_{use} = 0.32*V$ in energy calculations related to the German building code EnEV. In table 2 both areas are given, in some cases there is a significant difference. KfW40 and KfW60 indicates a primary energy demand of 40 kWh$_{PE}$/(m²A$_{use}$a) for heating and DHW or 60 kWh$_{PE}$/(m²A$_{use}$a) respectively. It's a standard set by the German Kreditanstalt für Wiederaufbau KfW. The 3-Liter-house aims for 30 kWh$_{PE}$/(m²A$_{use}$a) with the same reference areas. The passive house standard is defined as 120 kWh$_{PE}$/(m²$_{NFA}$a) for the total energy consumption including all electrical household appliances, the heating energy demand is limited to 15 kWh$_{UE}$/(m²$_{NFA}$a). The zero house approach in this context uses the same calculation scheme as the passive house standard but includes a full renewable supply on an annual balance level.

The buildings studied were renovated from 2003 - 2007. In the process, primary energy demand for heating and domestic hot water was reduced on the average by 80 - 90 %, which was around 50 % below the current requirements of the German building directive EnEV (Figure 8.1-2). Furthermore, in some projects more ambitious goals, such as zero-energy concepts (Blaue Heimat, Roter Block), the passive house standard (Hoheloogstr. Tevesstr.), or the 3-liter standard (Freyastrasse) were pursued. During renovation, no one was living in the houses [211], [212] and [213]. The key building data are listed in Table 8.1-1. The measurements were evaluated for Rislerstrasse, Blaue Heimat and Freyastrasse [214] and [215]; detailed measurements are ongoing for all projects.

The two buildings in Rislerstrasse are three-storey residential complexes built in 1961. Similar layouts and designs allow us to compare the KfW40 energy standard, which was the goal for Rislerstrasse 1 - 5, to the KfW60 standard for Rislerstrasse 7 - 13. The main difference in these two buildings is the ventilation system. The building with the KfW40 standard has an air exchange system with heat recovery, while the KfW60 building has a simple exhaust ventilation system. A 60 kW gas-condensing boiler provides heat with the support of a solar thermal system (24 m² and 29 m² with 750 l of buffer storage, 500 l hot water tank).

In Heidelberg, Blaue Heimat is a three-story residential building constructed in 1951 to round off a block; it underwent thorough renovation. The energy renovation concept includes thermal optimization of the building envelope, the installation of a central air exchange system with heat recovery, and a gas-fired cogeneration unit (50 kWel/80 kWth) with a 3000 l buffer tank. This serves two not yet renovated neighbouring buildings as well. The goal was to offset all carbon dioxide emissions over the year to become a "zero house" [212]. Two 92 kW low-temperature boilers were already installed and were retained to cover peak loads. Radiators distribute heat into the rooms.

The projects at Freyastrasse 42 - 52 in Mannheim are two-story buildings from the 1930s designed as terraced houses. Each unit has a separate air exchange system with heat recovery. Various systems were used and investigated for the distribution of heat. Overall, five types of systems were studied: three air heating systems with various control systems; a radiator heater; and a panel heating system. A cogeneration unit (Stirling motor 0.85 kWel/6 kWth) and a 185 kW gas-condensing boiler, both of which were installed in an adjacent building, provide heat. Hot water comes from an instantaneous system to reduce losses in storage and distribution.

Table 8.1-1
Analyzed German Demonstration Projects

Project		**Heated NFA[m²]**	**Floor Area according to EnEV A_{use} [m²]**	**H_T' [W/(m²K)]**	**Envelope area [m²]**	**A/V [1/m]**	**Primary energy consuumption [kWh/(m^2_{Use}a)]**	**Ventilation system with heat recovery**	**Cogen unit gas ○ rape seed oil ●**	**Solarr thermal / Photovolataic○**
Rislerstrasse Freiburg		1232/ 1640	1633/ 2181	0.27/ 0.35	2939/ 3494	0.58/ 0.52	39.0/ 59.0	● ○		●
Roter Block Freiburg		-	3871	0.84	4775	0,30	6.0		●	
Blaue Heimat Heidelberg		-	4689	0.31	5705	0.39	34.0	●	○	
Hoheloogstrasse Ludwigshafen		750	960	0.23	1473	0,35	31.2 (meas.)	●		○
Tevesstrasse Frankfurt		2244/ 1350	2867/ 1788	0.25	4023/ 2252	0.45/ 0.46	28.0/ 38.0	●		●
Guter Hirte Ulm		G 887 K 482 P 393	1042 516 425	0.57 0.46 0.51	1700 1181 668	0.52 0.73 0.51	45.9 44.5 45.8	 ● ●		○ ● ●
Freyastrasse Mannheim		1150	2099	0.18	3285	0.5	37.0	●	○	

Table 8.1-2
An overview of the German projects studied in IEA SHC TASK 37.

Project	**Specifics**	**Owner / planner**	**Institute responsible for measurements**
Rislerstrasse 1 - 5, 7 - 13 Freiburg	KfW40 and KfW60 standard	Owner: FreiburgerStadtbau GmbH Architect: B. Thoma - G. Henninger-Thoma Building services / energy concept: Lenz / Stahl + Weiß	ISE
Roter Block Freiburg	Protection of façade	Owner: Freiburger Stadtbau GmbH Architect: Huller, Banzhaf + Partner Building services / energy concept: Fischer / Stahl + Weiß	ISE
Blaue Heimat Heidelberg	"Zero" house	Owner: GGH-Heidelberg Architect: J. Gerstner, Heidelberg Building services / energy concept: solares bauen GmbH	ISE
Hoheloogstrasse Ludwigshafen	Passive house renovation	GAG Ludwighafen Building services / energy concept: PHI	PHI
Tevesstr. Frankfurt	Passive house renovation	AGB Frankfurt Architect: Grenz/Rasch Building services / energy concept: Baumgartner/ PHI	PHI
Guter Hirte Ulm	Vacuum insulation	Catholic congregation of Bofingen Energy concept: IBP	IBP
Freyastrasse Mannheim	"3-liter house"	Owner: GBG Mannheim Energy concept: IBP / IGE	IGE / IBP

8.1.3 Results

Measurements were based on the monthly readings of heat counters and power meters (Rislerstrasse 05/06 and 06/07; Blaue Heimat 06/07 [214]) as well as on detailed measurements (Freyastr 05/06 [215]). The heated floor area was used for comparisons of specific consumptions (see Table 8.1-1). Figure 8.1-4 and Figure 8.1-3 show values measured for consumption of useful energy, end energy, and primary energy for heating, hot water, auxiliary energy, and ventilation. Figure 8.1-5 shows the energy flow chart.

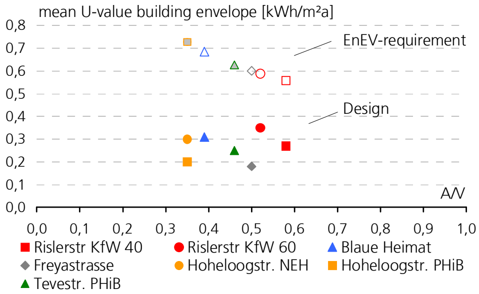


Figure 8.1-1
Comparison of U-values of the analzed projets vs. the German standard requirements as of 2002

Heat consumption space heating

Despite the higher insulation standard of the KfW40 building in Rislerstrasse, heating

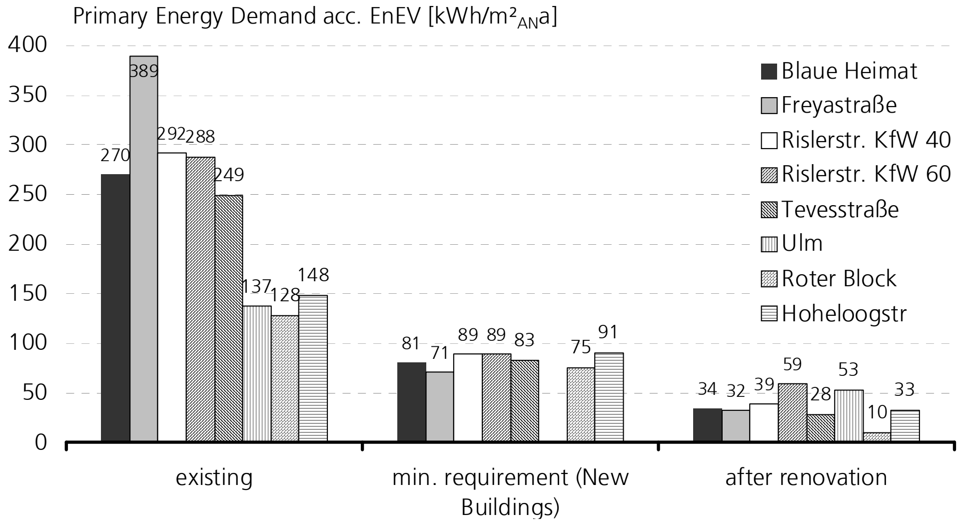


Figure 8.1-2
Comparison of calculated primary energy demand for heating, hot water and electricity for fans and circulation

energy consumption at 31 kWh/(m²NFAa) was not much lower than in the KfW60 building which had an exhaust ventilation system without heat recovery needing 33 kWh/(m²NFAa). The measurement data do not reveal whether inhabitants were heating their rooms to different temperatures or leaving windows open differently. The KfW40 house is 5 kWh/(m²Ausea) above the target values, while the KfW60 house is 15 kWh/(m²Ausea) below them. Adjusted for weather conditions, consumption of useful heat in the Blaue Heimat building was 18.9 kWh/(m²NFAa), which was slightly below the target. Consumption of heating energy in the town houses in Freyastrasse varied between 11 kWh/(m²NFAa) and 60 kWh/(m²NFAa), with an average of 29 kWh/(m²NFAa). The various heating transfer systems used cannot be properly assessed because user behaviour differed so greatly. It can be stated, however, that by using floor or wall heating systems the temperature stratification can be reduced in buildings with open staircases. The electricity used for mechanical ventilation and heating pumps was within the expected range in all buildings.

Heat consumption domestic hot water

One salient finding in the three buildings at Blaue Heimat, Rislerstrasse KfW60 and KfW40 was the relative high hot water consumption at 28 kWh/(m²NFAa) (including circulation). This value is 70 % above the target. In addition, Blaue Heimat had 6 kWh/(m²NFAa) of distribution and storage losses due to the central system used. Energy consumption for hot water was much lower in Freyastrasse at 18.4 kWh/(m²NFAa), which was below the target value; part of the reason was the lower number of occupants and the lower circulation losses.

Energy supply

The cogeneration unit in the Blaue Heimat building provides almost all of the heat required. On the average, the cogeneration unit had an efficiency of 89 % and covered 96 % of the heat demand. Thus the possibility of a high CHP fraction as an important part of a net zero energy strategy is shown. Even though the pipes were well insulated (200%

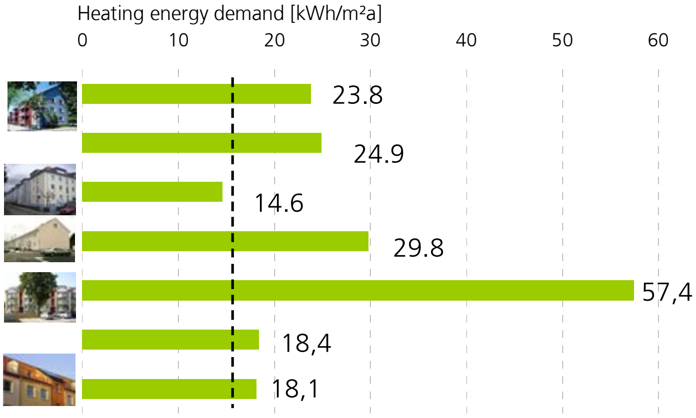


Figure 8.1-3
Heating energy consumption for the buildings:

Risler KfW40
Risler KfW40
Balue Heimat
Freyastr
Hoheloogstr. NEH
Hoheloogstr. PHiB
Tevestr PHiB

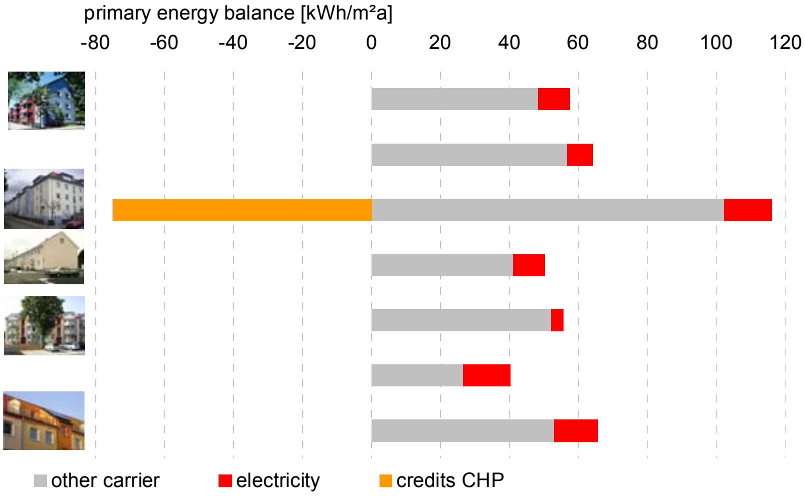
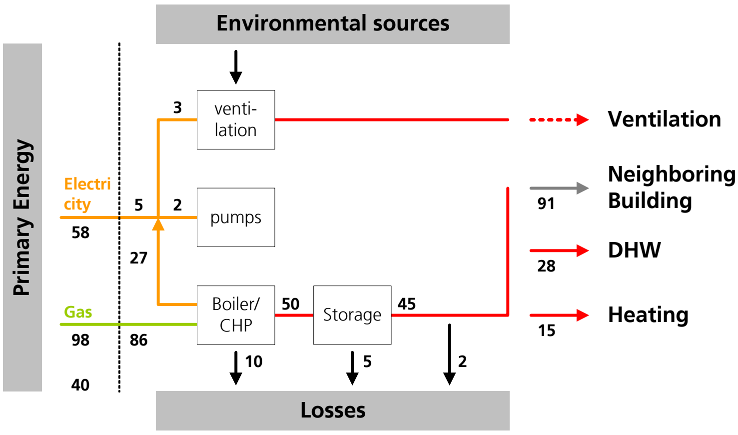


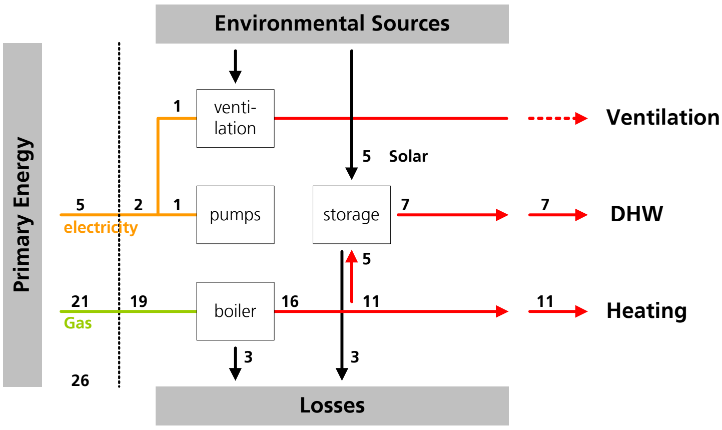
Figure 8.1-4
Primary energy balance for the buildings:

Risler KfW40
Risler KfW40
Balue Heimat
Freyastr
Hoheloogstr. NEH
Hoheloogstr. PHiB
Tevestr PHiB

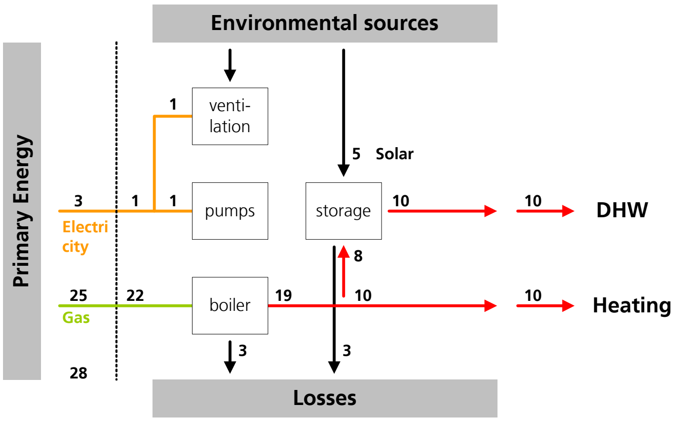
Figure 8.1-5
Energy flow diagram:



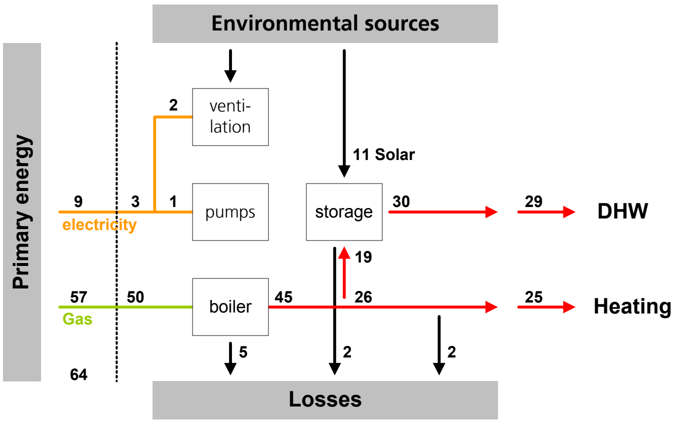
Rislerstrasse KfW40;



Rislerstrasse KfW60



Freyastrasse



compared to the German standard) the storage and distribution losses become a non neglecting part of the delivered heat. The chopping of the CHP unit was suppressed applying an appropriate sizing of the storage.

In Rislerstrasse, the gas-condensing boiler and storage tank had an average efficiency of 85 % in 05/06 and 91 % in 06/07, which were as expected. The solar collectors covered 40 % of hot water demand in Rislerstrasse, which is a quarter of the overall heat demand.

Primary Energy

Primary energy consumption was 77 kWh/(m$^2_{NFAa}$) (Rislerstrasse KfW60), 69 kWh/(m^{2}NFAa) (Rislerstrasse KfW40), 51.8 kWh/(m^{2}NFAa) (Freyastr) and 37 kWh/(m^{2}NFAa) (Blaue Heimat) applying the credit method for CHP in the latter case. Thus the results are slightly above the target.

8.1.4 Conclusions

The results allow the following conclusions to be drawn about the buildings and their energy concepts:

Energy: the targets projected during planning were reached in actual operation and even surpassed in some cases. The building standards studied can be considered state of the art even by today's standards. Renovation can bring old buildings close to the passive house standard despite specific problems, such as ventilation, air tightness, and thermal bridges. The strict standard for the building itself means that parameters influenced by users (such as hot water consumption and ventilation) become more important, as do relatively minor energy flows (such as distribution and storage losses), which then have to be taken into greater consideration during planning. The main consumption parameters are hot water and electricity; for instance, the figures for Blaue Heimat were: heating: 18.9 kWh/(m^{2}NFAa), hot water: 28.4 kWh/(m^{2}NFAa), electricity: 24.3 kWh/(m^{2}NFAa). Even though they were taken into consideration during planning, storage and distribution losses were almost half as high as the actual heating energy consumption (insulation of the distribution system in Blaue Heimat: 200 %, Rislerstrasse: installation in attic insulation)

- Supply Systems: solar thermal collectors make a significant contribution. If storage is properly dimensioned, a cogeneration unit can run at very high capacity utilization rates, thereby functioning as an efficient supply system after renovation and being an important part of a net zero energy strategy.
- Users: A comparison of heating energy consumption in the buildings in Rislerstrasse revealed only a slight difference between the two energy standards, which was not projected. The reasons may be the influence of user behaviour (comfort requirements and ventilation), a difference in the number of people in the buildings, or less efficient heat recovery in the ventilation system.

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8.2 Insights from Exemplary Housing Renovations with Solar and Conservation

Robert Hastings

8.2.1 Introduction

60 exemplary housing renovations achieving dramatic energy savings have been documented in brochures in Subtask B of Task 37 of the IEA-SHC Program. This summary offers insights from a collective look at these brochures from ten countries:

AT, BE, CA, CH, DE, DK, I, NL, NO and SE.

The successes of the renovations results from a combination of strategies, including:

- extreme conservation measures
- installing efficient systems for ventilation and heat production
- adding a solar thermal system or PV-system
- minimising ecological impact
- Re-designing the housing to enhance living quality.

The first steps are consistently to add insulation while eliminating air leakage and replacing old windows with very ones. Most projects compliment such conservation measures with a solar thermal system. In locations with high kWh buy-back prices, a roof mounted PV system has been added to the renovation package.

Performances of the modernisations are impressive. Primary energy consumption for space heating and water heating has been reduced up to 90 percent. This is all the more impressive because it reflects the source energy needed to produce the energy, not just end energy. Equally impressive is the dramatic improvement in the living quality of the projects, which in most cases was the motivation.

It is interesting to examine the different approaches taken across Europe as well as the three examples from Canada to achieve these savings. Each country and building culture adds an insightful dimension to finding the most cost effective, energy saving and quality of life winning solutions.

The experience from the projects is summarised here to encourage housing owners to be ambitious when planning a renovation. A mediocre renovation blocks a deeper, more effective renovation for decades. If the inflation of energy costs is considered, the marginal costs of energy saving measures during a modernisation will pay back nicely.

8.2.2 Architectural measures:

The three most frequent measures are: exterior insulation, a new balcony structure to eliminate thermal bridges and enlarge the useable space, and redesigning the floor plan. Sunspaces, popular in the 1980's, were added in only four projects. However, if enclosing balconies with glass is added to the number of sunspaces, the total is 13. Noticeably small is the number of projects using interior insulation (perhaps due to risk from moisture and loss of room space) or vacuum insulation (costs and worry about longevity). The numbers of projects with specific architectural measures out of the total of 60 projects are

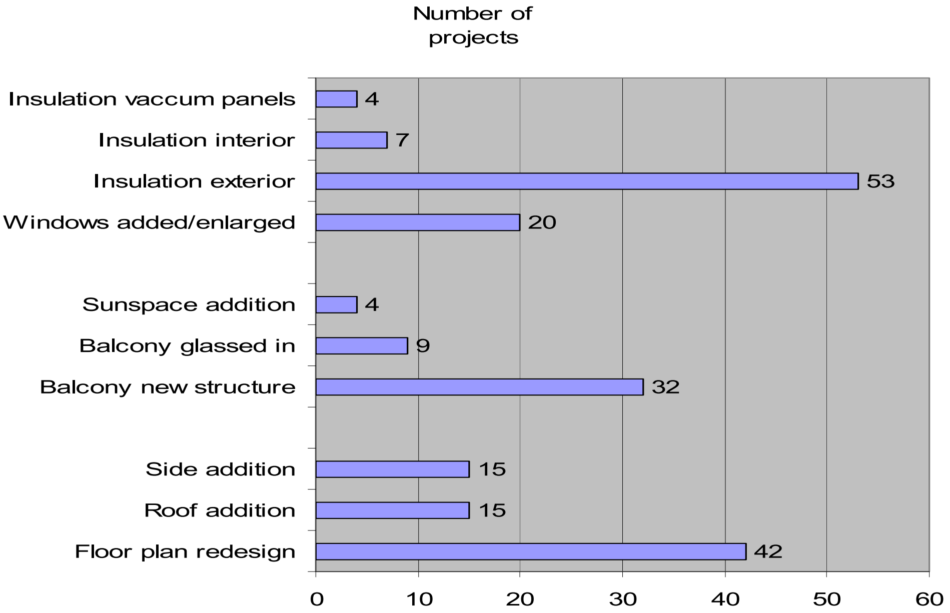

Figure 8.2-1
Number of projects including architectural changes

shown in Figure 8.2-1

8.2.3 Insulation of the envelope:

Figure 8.2-2 shows how insulation values of the envelope were reduced. The biggest improvement was for windows (frame and glass). Most renovations used triple glazing and high quality window frames. Good U-values are all the more important, given that in 19 projects the window area was increased

The walls and roof, with more surface area, lead to the greatest savings. Roof insulation is especially important for summer comfort. Basement ceiling insulation improves comfort on the ground floor, but with resulting loss of comfort for basement uses, i.e. as wash rooms or hobby work rooms). Ten projects reported to meet the Passive House Standard and three almost met it.

8.2.4 Technical Systems:

New technical systems were a major part of the modernisations (Figure 8.2-3).

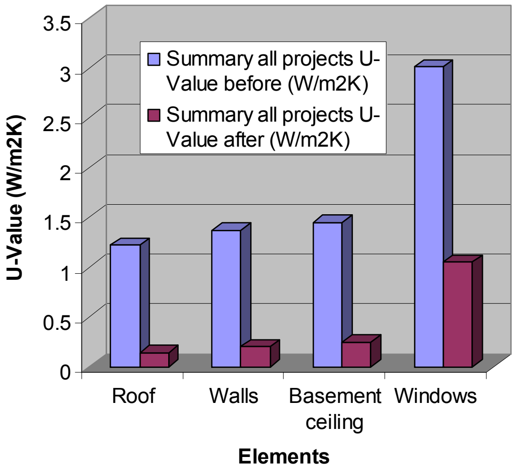

Figure 8.2-2
U-values of envelope elements before and after modernisation

34 projects had active solar thermal systems, of which six helped meet both domestic hot water and space heating demand. Vacuum tube collectors were used in 13 projects.

PV-systems were installed in 18 projects, totalling 132 kWp. The largest systems are on the apartment buildings, with five systems of 10 to 19 kWp (Figure 8.2-4).

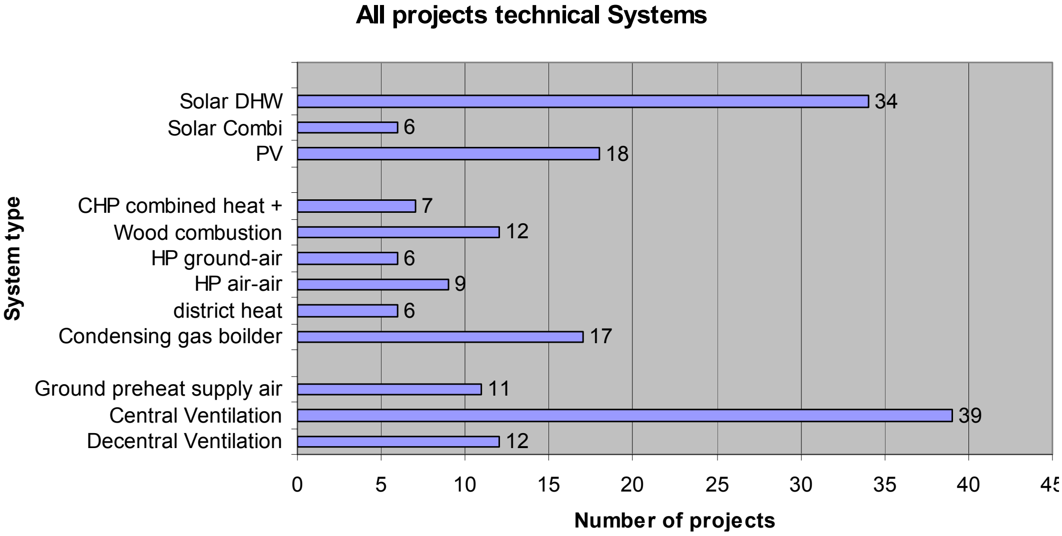

Figure 8.2-3
Types of systems used in the projects

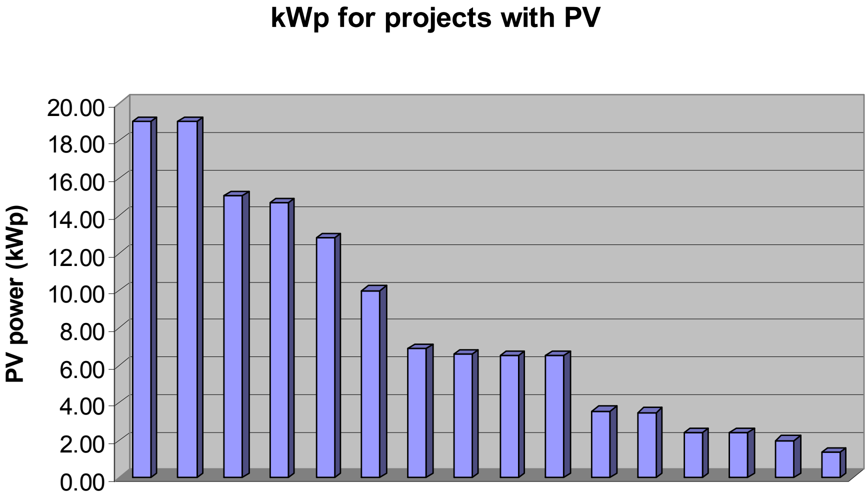

Figure 8.2-4
PV nominal peak power kWp of projects

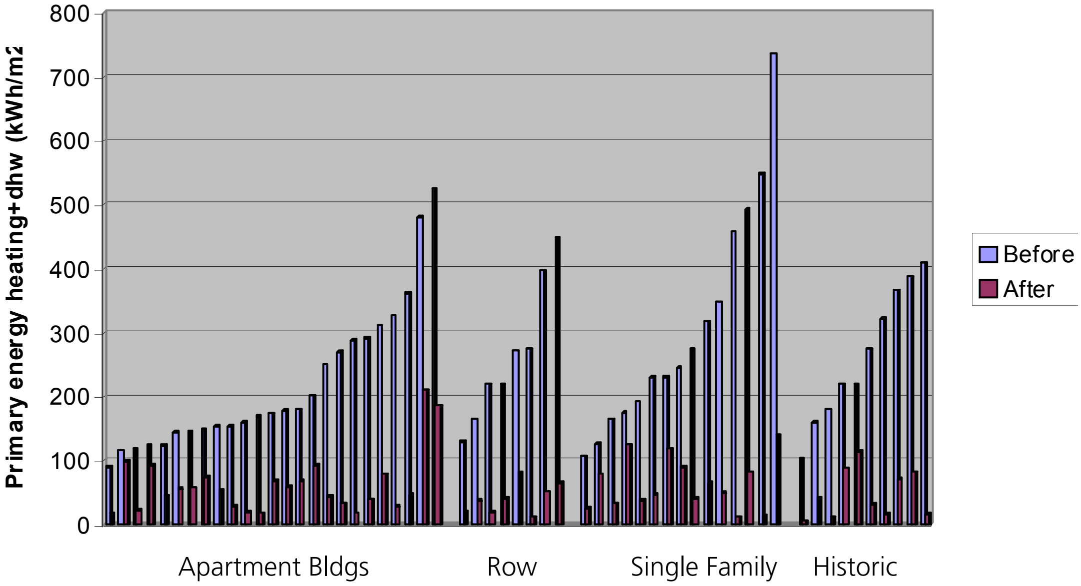

Figure 8.2-5
Percentage energy savings of each

Remaining heating demand was most frequently met by a condensing gas boiler (most there before the renovation). Next were heat pumps (15 with 6 using the ground as a heat source). 12 projects used wood combustion. Six projects incorporated combined heat and power plants (CHP), of which one used a Stirling motor (521 Row houses in Manheim). Three projects still had oil fired heating.

Of the 60 projects, 51 had mechanical ventilation with some form of heat recovery and most were central systems (39). Non-central systems included room ventilation units, i.e. thru-wall units or window frame slits. 11 projects preheated supply air in buried earth channels. One project used façade-mounted solar air collectors to preheat supply air entering the room behind the wall (512 APT for Elderly in Stuttgart DE). The average efficiency of the heat exchangers was 84%. An efficiency higher than this is probably unrealistic in actual usage.

8.2.5 Performance:

On average, energy savings for space heating, water heating and electricity for technical systems amounted to 76 percent for the sixty projects. Ten projects achieved 90 percent or more savings. It can be observed that by all housing types dramatic energy savings are possible (Figure 8.2-5).

The greatest savings for this collection of renovations were achieved by the row houses (84%) followed by the historic housing (81%). Of course, historic housing start from the highest energy consumption, but it has more limitations. Not graphed are the two projects with added attica apartments, because there is no before energy consumption for comparison.

The renovations by housing type and country are shown in Table 8.2-1. A brief summary of observations by housing types follows.

8.2.6 Apartment buildings

The most common renovation strategies used in the 25 documented projects were:

- Add 200 to 300 mm of insulation and a new exterior to the facades of the building.
- Eliminate the thermal break of balconies (28 projects), typically by cutting off the old, projecting balconies and constructing new, free-standing balconies. Alternatively, the balconies were glazed in. Thus the thermal bridge is within a sun-tempered space (9 projects). In one case, the balcony was fully insulated to become part of the living space.
- Tighten the envelope and add mechanical

Figure 8.2-6
Added glazing to make a bright, daylit stair tower. 612 APT in Engelsby (Photos: Stærmose & Isager Architects)

Country	Apartment APT (10)	Row house ROW (20)	Single Family SFH (30)	Historic HIS (40)	Attic Apt ATC (50)	Total
100 Austria AT	4	0	5	2	1	12
200 Belgium BE	1	3	0	1	1	6
300 Canada CA	0	0	3	0	0	3
400 Switzerland CH	6	0	3	3	0	12
500 Germany DE	8	1	1	3	0	13
600 Denmark DK	2	1	0	0	0	3
700 Italy IT	0	0	0	1	0	1
800 Netherlands NL	0	2	1	0	0	3
900 Norway NO	2	1	2	0	0	5
1000 Sweden SE	2	0	0	0	0	2
Total	25	8	15	10	2	60

Table 8.2-1
**Note: the brochures are keyed by country code: (100 – 1000) and Housing type:*

(Apartments: 10 – 19, Row houses: 20-29, Single family: 30-39, Historic: 40-49, Attica 50-).

ventilation with heat recovery (average efficiency 82%).

- Add a solar system. Twelve projects invested in a solar thermal system, two of which were combi systems. Eight projects invested in a photovoltaic system, several of which are large systems from 10 to 19 kWp.
- Replace the heating system with a renewable energy system. Many system types are represented here: Three projects use a heat pump of which one used the ground as a heat source. One project has a combined heat and power system. Two projects use wood pellets, and the remainder use a condensing gas boiler or are connected to district heat. The Norwegians heat using water power (hydro-electric).

The average energy consumption before and after the renovation showed a 69% reduction in primary energy consumption from 220 to 63 kWh/m2a.

8.2.7 Row and Single Family Housing

Typical actions taken in house renovations from AT, BE, CA, CH, DE, DK, NL and NO were:

- Add insulation to the attic and/or basement ceiling
- Replace the windows and possibly entrance door
- Insulate facades and add a new exterior finish
- Replace the boiler and hot water heater
- Add a solar system to heat hot water

Figure 8.2-7
432 SFH Ostermundingen CH
(Photo: Christian Zeyer)

- Add mechanical ventilation heat recovery
- Add PV Panels for electric generation.

Looking at all eight row house projects, primary energy for heating, hot water and elec. for technical systems was reduced from 310 to 64 kWh/m2a, an 84% saving! Savings by the single family were from 310 to 64 kWh/m2a or a 74% savings on average.

8.2.8 Historic Housing

The renovation of housing under historic protection has more limitations. The typical actions taken in the projects (AT, BE, CH, DE, DK, IT) in order of carrying them out (except where an action was urgent) are:

- Add insulation to the attic and/or basement ceiling
- Add modern window sash and glazing inside existing windows
- Replace the boiler and hot water heater
- Insulate walls on the interior
- Add mechanical ventilation with a heat exchanger
- Add solar collectors and PV Panels on rear roof slopes not visible from the street.

Considering the constraints on historic buildings the savings in primary energy are impressive: 264 to 48 kWh/m2a, or an 81% reduction!

8.2.9 Attica Apartments

Building new housing on the roof of existing buildings is a great real estate opportunity but with limitations. In order not to overload the existing building structure, usually a light weight construction is chosen. To comply with setback profile requirements often the attica apartments, if they are more than one storey, are terraced back from the edge of the roof. Their position affords maximum solar exposure for solar thermal or PV panels. Such apartments can be particularly striking living units, with views, better natural ventilation and less street noise. Their high rental income or sales price often pays for the entire renovation of the building. This is, however, not a sustainable financing solution; the next renovation in 20 or 30 years will have to be financed by some other means.

The typical actions taken to achieve high performance are:

- Generous wall, and especially roof insulation (greatest summer overheating load)
- Large, highly insulating windows to maximise view, passive solar gains and daylight without compromising energy and comfort performance.
- Including a solar hot water and ideally space heating system.
- Add PV if the payback price for electricity justifies the investment.
- Add mechanical ventilation with a heat exchanger

8.2.10 Conclusions

The experience from these sixty projects consistently shows that measures to save energy alone would be absurdly expensive with little hope of paying back the investment costs with energy savings! However, when a renovation is essential for whatever other reasons (i.e. to fix something broken or badly deteriorated), then the marginal costs of investing in high energy performance makes is very sensible. It also makes sense to think through a concept for the whole building, rather than piece-meal fixing parts as they break. Within such a framework, energy conservation measures do, indeed, offer a good return on investment. Furthermore, given that a planer must be engaged, permits obtained, scaffolding erected, etc. and then adding a solar system will never be a better bargain. The decision to invest in PV-panels depends on the "buy-back" kWh price offered by the local utility. To not make the investment in high energy performance when housing is renovated is a crime against future generations of owners, who will with absolute certainty have to heat, cool, ventilate and light the building with very expensive energy from perhaps unreliable sources.

It is inspiring to review the individual projects in these 60 brochures to get ideas for concepts and details, and examine what performance results can be expected. Following is a table of the brochures listed by country (with initials for the housing type and country). These housing owners are indeed pioneers and their successes, with energy savings up to 90 percent, will hopefully encourage other housing owners to undertake equally ambitious renovations.

Figure 8.2-8
Placing new cornices over insulation in 142 HIS Purkersdorf AT
(Photo: Architekturburo Reinberg)

Figure 8.2-9
Attica apt. Terraces of 251 ATC Brussels (Brochure: J. Desmedt, J.Cre, W. Hilderson)

List of the 60 project brochures by country

AUSTRIA

111	APT on Makartstrasse, Linz AT
112	APT in Dornbirn AT
113	APT in Kierling AT
114	APT for Elderly in Landeck AT
131	SFH in Kufstein AT
132	SFH in Mautern AT
133	SFH in Pettenbach
134	SFH in St. Martin AT
135	SFH in St.Valentin AT
141	HIS apartments in Irdning AT
142	HIS Villa in Purkersdorf AT
151	ATC Attica Innsbruck - AT

BELGIUM

211	APT social housing Sterrenveld BE
221	ROW conversion Brussels BE
222	ROW Henz-Noirfalise, Eupen, BE
223	ROW semi-detached, De Pinte, BE
241	HIS in Herselt BE
251	ATC Atttica apts in Brussels BE

CANADA

331	SFH in Toronto CA
332	SFH Reep in Kitchener CA
333	SFH in Kingston House, Ontario CA

SWITZERLAND

411	APT 2-family in Stansstad CH
412	APT in Ostermundigen CH
413	APT in Staufen, CH
414	APT in Volketswil1 CH
415	APT on Segantinistr Zurich,CH
416	APT in Birmensdorferstr., Zürich CH
431	SFH in Lanterswil CH
432	SFH in Ostermundigen CH
433	SFH in Walenstadt CH
441	HIS Elderly Home, Bern CH
442	HIS apartments in Zurich CH
443	HIS CAYLA in Geneva CH

GERMANY

511	APT Rieslerstr. Freiburg DE
512	APT for elderly in Stuttgart DE
513	APT BlaueHeimat in Heidelberg, DE
514	APT Hoheloogstr.,Ludwigshafen, DE
515	APT Schlesierstr., Ludwigshafen, DE
516	APT Teverstr., Frankfurt DE
517	APT Jean-Paul-Platz in Nürnberg DE
518	APT+Nursery in Ulm-Böfingen DE
521	ROW houses in Mannheim DE
531	SFH-Rectory, Ulm-Böfingen DE
541	HIS apts. Roter Block, Freiburg DE
542	HIS Sodastr., Ludwigshafen, DE
543	HIS Speyer DE

DENMARK

611	APT in Albertslund, DK
612	APT Tower in Engelsby, DK
621	ROW house in Albertslund, DK

ITALY

741	HIS in Modena IT

NETHERLANDS

821	ROW Kroeven-Roosendaal NL
822	ROW Roosendaal 112 NL
831	SFH PIAF® in Sint Pancras NL

NORWAY

911	APT cooperative Myhrerenga NO
912	APT Terrasses Husby in Stjørdal, NO
921	ROW house with annex in Oslo NO
931	SFH Wachenfeldt in Orkanger in NO
932	SFH Log home, Kongsberg NO

SWEDEN

1011	APT bldg in Brogården, Alingsås SE
1012	APT bldgs Backa Röd, Göteborg SE

Annex

Energy Glossary

Florian Kagerer

Energy terms

Coefficient of Performance COP [-]

The ratio of the power output to the power input of a system

Primary energy PE [kWh]

Energy that has not been subjected to any conversion or transformation process. Primary energy may either be resource energy or renewable energy or a combination of both. For a building, it is the energy used to produce the energy delivered to the building. It is calculated from the delivered amounts of energy carriers, using conversion factors

Delivered energy/ site energy [kWh]

Energy supplied to the building through the system boundary from the last market agent to satisfy the energy requirements for heating, cooling, ventilation, domestic hot water and lighting. No adjustment is made in regard to energy losses occurring in the generation, transmission, and distribution of energy. Delivered energy is sometimes referred to as “site energy”

Effective energy/ useful energy [kWh]

Energy for domestic hot water, heating, lightning, cooling etc.

Embodied energy [kWh]

Embodied energy describes the energy required to manufacture a product. A product that requires large amounts of energy to obtain and process the necessary raw materials or a product that is transported long distances during processing or to market will have a high embodied energy level

Auxiliary energy [kWh]

The quantity of energy used by pumps, ventilators, controls, etc. to transform and transport the delivered energy into effective energy for lightning, heating, domestic hot water, etc.

Energy demand [kWh]

Calculated quantity of energy for all applications and given end use. Energy to be delivered by an ideal energy system (no system losses are taken into account) to provide the required service to the end user (e.g. to maintain the required internal set-point temperature of a heated space).

Energy requirements [-]

Energy supplied to the technical system (system losses are taken into account) to provide the required service.

Energy requirements can be specified for each subsystem (e.g. distribution, storage) and express the energy supplied to the subsystem

Net energy [-]

Energy supplied by the energy system to provide the required services, e.g. maintaining the building at the specified internal temperature, ventilating a space, lighting a space. Recovered losses and gains are taken into account

Energy consumption [kWh]

The actual measured quantity of energy needed for heating, cooling, ventilation, hot water heating, lighting, appliances etc. (metering)

Heat demand [kWh]

The calculated quantity of energy for heating and domestic hot water

Heat consumption [kWh]

The measured quantity of energy for heating and domestic hot water

Energy balance terms

Generation losses [kWh]

The energy that is lost during the process of energy generation.

Distribution losses [kWh]

In buildings with a high standard regarding the insulation of the envelope, energy lost through the distribution system becomes more significant.

Storage losses [kWh]

The energy that is lost during storage (e.g. heat energy that is lost during hot water storage in a boiler).

Exergy [-]

Energy is made up from exergy and anergy. Exergy is the part of the energy that can be transformed into any form of energy within defined boundary conditions. Anergy is the part of energy that can not be transformed in exergy.

Envelope boundary

Defines limits, i.e. the energy generated or consumed within the boundary of the building site.

Zero energy/ Zero emission

All electric approach

Heating/ Cooling might be based on high COP heat pumps/ chillers. Indirect emissions can be avoided with grid electricity based on 100% renewables

All grid approach

Heating and cooling are supplied by a local or district heating/ cooling network using only renewable energy (e.g. biomass)

All renewable approach

A local heating supply by combustion of biomass in combination with solar thermal collectors for hot water or space cooling and grid electricity based on renewables

Local balance approach

A grid-connected local electricity generation with photovoltaic or building integrated cogeneration. The use of non renewable energy is balanced (in units of primary energy or carbon emission) over a yearly cycle by equivalent credits

Global balance approach

Local use of non-renewable energy or emissions is balanced over the lifetime of a building by additional investment in non-local renewable energy supply systems (e.g. wind farms).

A CO2 trading system for the building sector is also thinkable with reinvestment in renewable energy of efficiency programs

Area definitions

Form factor A/V [m^{-1}]

The ratio between the building envelope area and the gross building volume

Building envelope area A [m^2]

Total external area of the building envelope enclosing the heated volume – façade (including doors and windows), roof and ground – and measured at the outer boundaries of the building

Gross volume V [m^3]

The heated building volume calculated on the basis of the outdoor dimensions

Net heated volume V_N [m^3]

The heated volume calculated on the basis of the indoor dimensions

Net heated floor area A_N [m^2]

The sum of the floor areas of all heated rooms including heated corridors and heated internal stairways but not unheated rooms.

Building categories

Net zero energy building

A building where the net energy consumed over a year is matched by an equal amount of energy produced on site

Zero emission building

A building without energy generation related CO2 emissions

Net zero emission building

A building with CO2 emissions balanced over the course of the year. Consumption related CO2 emissions are counterbalanced by energy generation based on renewable energy. This is possible on-site and off-site

Passive House

According to the definition provided by the Passive House Institute, the following requirements have to be fulfilled:

A maximum end-energy space heating demand of 15 kWh/m²a, a primary energy demand for all end-uses including electricity for appliances which is not higher than 120 kWh/m²a, and an air-tightness of the envelope of 0.6 by 50 Pa over the under pressure

3 litre house

A building which only needs three litres of oil per m² for heating. This corresponds to 30 kWh/m²a

Low energy building

Buildings with the explicit intension of using less energy than standard buildings. However, no specific requirements are defined

Plus energy building

A building where more primary energy is produced annually than consumed. Typically a net zero is reached by generating on-site electricity which has a high primary energy replacement value and can therefore be credited against thermal energy demand which has a lower primary energy factor

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