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Innovative curtain wall with solar preheating of ventilation air and integrated control system

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Abstract

There is a growing demand for curtain walls within the European Union, coming mainly from the commercial sector and especially targeted to office buildings. Despite recent efforts on heat loss mitigation (relying on additional glass panes, coatings or thermal breaks to framing elements) curtain walls remain a significant contributor to the energy consumption of such buildings.

This paper presents the design and development of an energy-efficient alternative to conventional curtain wall systems, achieving equivalent transparency and aesthetics with greater comfort and reduced energy consumption. An integrated air cavity, sandwiched between glazing layers of thoroughly selected properties, harvests heat from both incident solar radiation and transmission losses recovered from the indoor environment. The system can supply the airflow required for ventilation with preheated fresh air, thereby reducing energy consumption in the heating season, and even delivering net gains in favourable conditions. Thereby the building envelope acquires an active role within the ventilation system, acting both as a solar collector and a heat recovery device.

Whenever solar gains are not sought, a bypass element allows the natural ventilation of this air cavity, acting as a ventilated façade. An integrated control system with embedded electronics and actuators allows for a smart control of the system with no intervention required from the user.

1 Introduction

The European Commission is aiming to achieve a reduction of 20% in greenhouse gas emissions and primary energy use, as well as a 20% share of renewable energy, by 2020 [1]. Given that buildings currently represent 40% of the energy consumption of the European Union [2], the construction sector concentrates a great potential for improvement.

At the same time, European regulations are increasingly focused on ensuring an appropriate indoor air quality through ventilation requirements. However, the replacement of indoor air with external air results in an additional energy requirement for the HVAC systems of the building. Studies by the Air Infiltration and Ventilation Centre of the International Energy Agency (IEA) have determined that, following increasingly demanding requirements for insulation, airtightness and indoor air quality, energy losses associated with ventilation become much more significant, account for up to 50% of space heating or cooling needs in some cases [3].

Curtain walls are an increasingly demanded solution for building envelopes in the commercial sector. Despite the recent recession, curtain wall demand in Europe has continued to grow steadily. Office buildings constitute the predominant customer segment for curtain walls, accounting for over 55% of their European market share [4]. Curtain wall technology is also being increasingly adopted in many public buildings, and even for high-end residential projects. There is a strong trend towards prefabrication: industrialised modular curtain walls (unitized systems) have achieved a strong dominance within the European curtain wall industry, and already represent 65% of the market [4].

The exposure to natural light, the visual contact with the exterior, their technological appearance and the association with transparency are all assets of curtain wall construction. However, their energy efficiency performance tends to be extremely poor, typically leading to high transmission heat loss in winter and overheating problems in summer. Partial solutions such as additional glass panes and gas-filled air cavities, low emissivity coatings and thermally broken framing elements have been developed in an attempt to partially mitigate these problems.

This paper presents the initial design and development of an energy-efficient alternative to conventional curtain wall systems. It retains the advantages and appearance of the latter, while integrating solar harvesting and ventilation capabilities within the building envelope. In this way, a façade element that is usually considered an energy sink is turned into a technologically advanced component that is capable of harvesting and using solar gains in the ventilation of the building.

2 Concept and design of the system

The architectural solution chosen for the curtain wall is based on a modular concept, achieving both aesthetic and functional integration with the main ventilation system of the building. The interstitial air cavity of a double-skin glazed façade is used for harvesting heat from solar energy and recovering transmission losses from the indoor space. This air cavity is sandwiched between two transparent layers: single glazing to the external side, in order to maximise solar gains, and double glazing with a low-emissivity coating to the internal side, for preventing losses from indoor air and containing the solar gains within the cavity air.

The operation of the system is schematically depicted in Fig. 1. The base of the curtain wall accommodates a series of openings and filters for directing clean external air into the cavity. As the modules are vertically connected with each other, this air is heated as it rises, primarily by incident radiation from the sun, but also from heat transmitted through the inner glazing. The conditioned air is collected into a plenum at parapet level, and can be used as direct supply for the ventilation system. The control system operates a series of valves, which can either direct the preheated air to the inlet of the air handling unit or dissipate it to the outdoor space. In the latter case, the system operates as a rear-ventilated façade, evacuating excess heat by stack effect. In cold weather, the system aims to maximise renewable solar gains in order to (partially or fully) cover the heating demand of the building.

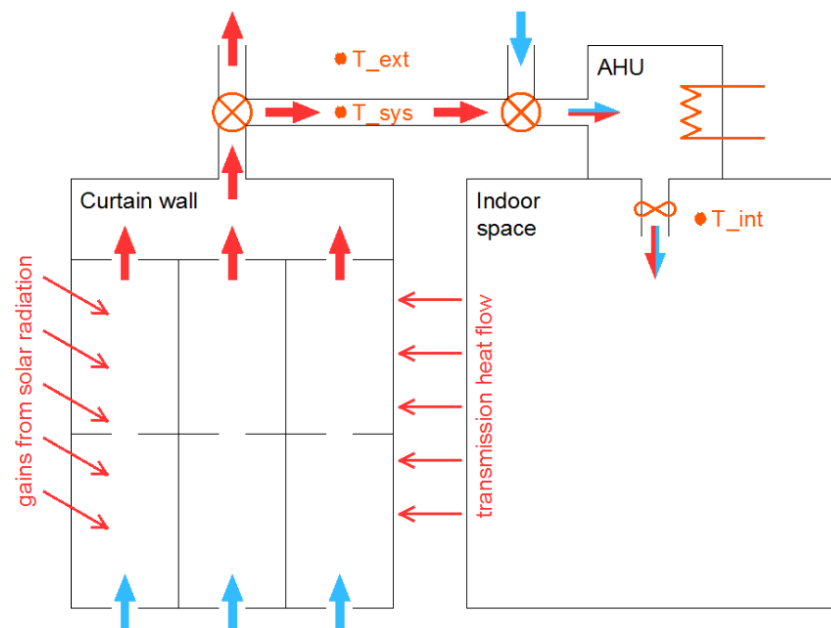


Figure 1: Diagram of the operation of the curtain wall and its integration with the air handling unit (AHU) of the ventilation system

The highest energy potential would be achieved by a south-oriented façade, yielding the most exploitable benefits in sunny winter days. The system allows for an immediate use of solar gains and, contrary to more complex active façades, it requires neither connection with intricate hydraulic circuits nor the use of additional products or materials with thermal storage capabilities.

The proposed curtain wall solution integrates a fully automated system for its intelligent monitoring, control and operation. Through a series of sensors and actuators (indicated in orange colour in Fig. 1), the smart control will operate:

- A series of valves directing the preheated air from the air cavity either to the air handling unit (powered by a ventilator) or to the external environment (dissipating heat by stack effect)
- The regulation of the power of the ventilator integrated within the air handling unit, as a function of required ventilation air flows
- The additional contribution for heating or cooling from the air handling unit of the HVAC system of the building, if the energy output from the curtain wall is not sufficient to maintain the indoor air within the set point temperatures desired by the user

3 Selection of glazing systems

The distribution of incident solar gains by transmission, reflection and absorption is graphically represented in the diagram of Fig. 2. Glazing systems can be characterized by their solar factor (g), transmittance (τ) and reflectance (ρ). The system aims to maximise the share of solar energy that is absorbed and re-emitted to the cavity (orange arrows in Fig. 2), while minimising heat gains towards the indoor space (red arrows in Fig. 2).

- For the external glazing element, a well-suited solution would be an absorptive single glazing with a high solar factor, while hampering direct solar transmission as much as possible
- For the internal glazing element, an ideal solution would be posed by an insulating glazing system combining a low solar factor and low reflective properties

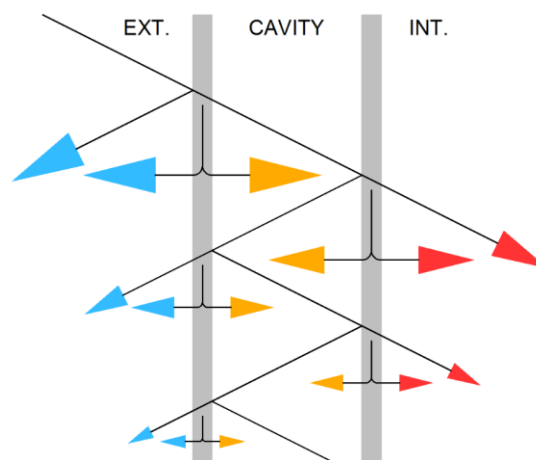


Figure 2: Graphical representation of the calculation model for solar heat gains of the indoor space (red) and of the air cavity (orange)

A parametric assessment has been carried out comparing different combinations of commercially available glazing systems as alternatives for the external and internal glazing elements of the system.

Table 1: Glazing systems considered for calculation

		solar factor, g	transmittance, τ	reflectance, ρ
■	Single-glazing A	0.89	0.88	0.08
●	Single-glazing B	0.85	0.83	0.08
▲	Single-glazing C	0.50	0.36	0.05
■	Double-glazing 1	0.33	0.29	0.35
■	Double-glazing 2	0.28	0.24	0.29
■	Double-glazing 3	0.21	0.18	0.33

Results are graphically depicted in the chart of Fig. 3, following the legend of colours and shapes indicated in Table 1. The combinations making use of the most absorptive glazing to the internal side (double-glazing 3) present the most convenient characteristics, achieving both greatest gains in the air cavity and lowest gains towards the indoor space. Regarding the external glazing, those with highest solar factor (single-glazing A and B) yield greatest gains into the air cavity, while a lower solar factor (single-glazing C) keeps internal gains at the lowest point. The combination B3 has been selected, as it

combines a fair share of solar gains within the air cavity ($f_c = 0.42$) with low gains to the indoor space ($f_i = 0.18$), while maintaining a good light transmittance.

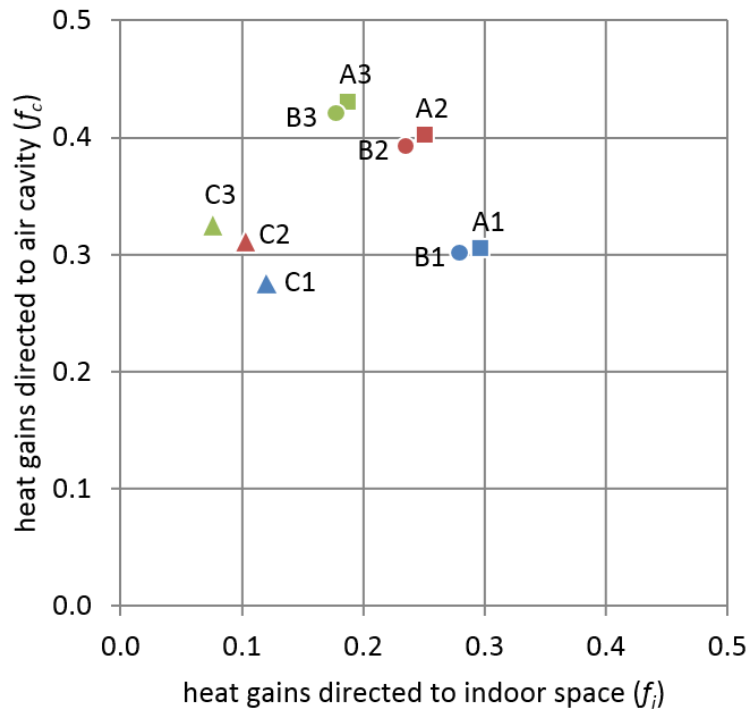


Figure 3: Share of incident solar irradiation directed to indoor space (horizontal axis) and to air cavity (vertical axis) for different glazing system alternatives

4 Calculation model

A stationary energy balance model has been developed for performing a prediction of the expected range of temperatures and air flows of the system. The height of the curtain wall is discretised into n elements, as shown in Fig. 4.

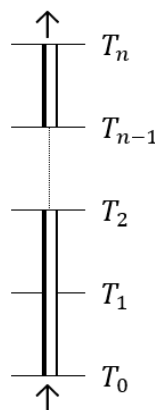


Figure 4: Model of curtain wall system discretised into n elements along its height.

For each finite element k , an energy balance equation is formulated by splitting solar gains into conduction heat losses (both to outside and inside) and heat delivered by convection to the adjoining finite element:

$$\phi \cdot f_c \cdot \frac{A}{n} = U_e \cdot \frac{A}{n} \cdot \left(\frac{T_{k-1} + T_k}{2} - T_e \right) + U_i \cdot \frac{A}{n} \cdot \left(\frac{T_{k-1} + T_k}{2} - T_i \right) + \dot{V} \cdot \rho_a \cdot c_p \cdot (T_k - T_{k-1}) \quad (1)$$

- Solar heat gains delivered to the air cavity are calculated multiplying the incident solar irradiance ϕ by the heat gain factor of the cavity f_c .
- Heat transfer through conduction between the air cavity and the outdoor and indoor environments is calculated from the thermal transmittances of the external and internal glazing systems U_e and U_i .
- The curtain wall is dimensioned to provide the necessary air flow \dot{V} to satisfy the ventilation requirements of the building. Spanish legislation [5] establishes a minimum renovation air flow of 12.5 dm³/s per person to satisfy indoor air quality requirements of office buildings. For an indicative calculation of occupancy, guidelines in Spanish fire safety regulations [6] have been followed, which estimate an average floor area of 10 m³ per person. Considering a storey height of 3 m, the aforementioned figures result in a requirement of 1.5 air changes per hour.

Starting from the first element at the base of the wall and assuming $T_0 = T_e$, the outlet temperature T_1 can be solved, which will then be the inlet temperature of the second element. In this way, energy balances for each element can be sequentially calculated, ultimately obtaining the outlet temperature T_k of the system. The temperature gain depends fundamentally on the amount of solar irradiation received ϕ , and to a much lower extent on the external and internal boundary temperatures T_e and T_i .

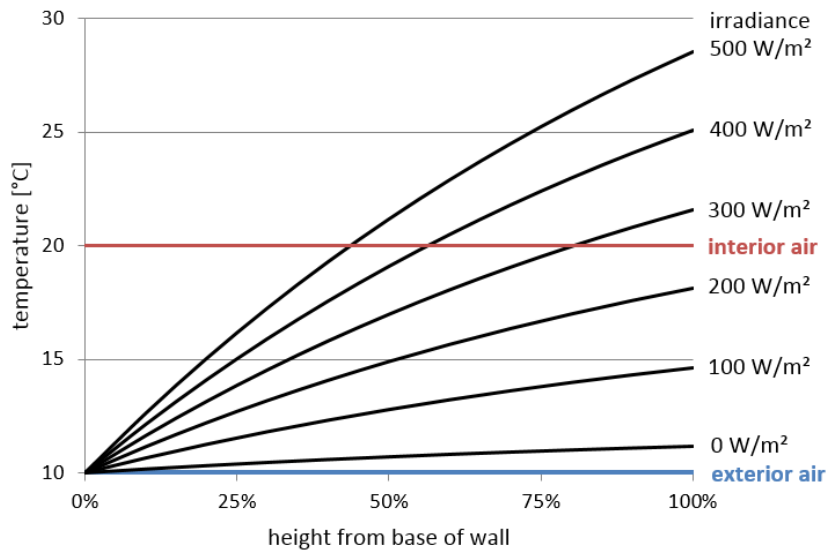


Figure 5: Temperature distribution along the height of a south-facing curtain wall, as a function of incident solar irradiance

The graph in Fig. 5 shows the temperature stratification calculated using Equation (1) for a south-facing air cavity, assuming an internal temperature of 20 °C and an external temperature of 10 °C, for a range of incident solar irradiance values from 0 to 500 W/m². The air flow requirement for ventilation

has been calculated for a building with a rectangular plan and a depth of 15 m perpendicular to the curtain wall (temperature gains are independent of the length and height of the curtain wall, provided that it covers the whole south-facing façade).

Results indicate that temperature gain is not linear along the height of the air cavity: a higher gain can be observed in the lowest modules, as heat losses increase with height (primarily due to a greater temperature difference with the exterior air). Interestingly, there is some temperature gain even in the absence of solar irradiation, given that part of the heat lost through the inner glazing system can be recovered through the air cavity.

5 Conclusions and further steps

The initial design and development of an energy-efficient alternative to conventional curtain wall systems has been presented. In the proposed solution, a glazed façade is turned into a smart building envelope integrating enclosure and ventilation functions. Indoor air quality demands are satisfied by harvesting and exploiting solar renewable energy, and the building envelope becomes an active element of the ventilation system.

For predicting the thermal performance of the system, a steady-state energy balance model based on discrete elements has been formulated. This calculation model forecasts significant temperature gains for a south-oriented façade, with a subsequent reduction the heating energy consumption associated with ventilation in cold temperatures.

An experimental validation of the system will be carried out to test its temperature gain and energy provision in a variety of weather conditions, the associated potential for reducing heating energy consumption, its functional integration with a ventilation and HVAC system, and the operation of the hardware and software elements of the control system. For this purpose, a full-scale test will be performed in the facilities of UXAMA Fachadas Singulares.

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