Double Envelope Unitized Curtain Wall for solar preheating of ventilation air

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Abstract: Despite recent efforts on energy performance improvement, curtain walls remain a significant contributor to the energy consumption of commercial buildings. A novel double envelope unitized curtain wall system is presented, aimed at the substantial improvement of the energy performance of glazed systems. Outdoor air is ventilated through an integrated cavity in its paths to the ventilation air intake of the air handling unit. In its path through the glazed envelope, the air is heated from both incident solar radiation and transmission losses recovered from the indoor environment. A substantial energy performance improvement is achieved by means of the preheating of fresh air. Energy consumption is reduced in the heating season, and even net gains above the heating demand are delivered under favorable conditions. By-pass elements are integrated to allow free cooling and natural ventilation when required in cooling mode. In this way, the double envelope also provides advantages in summer mode, where solar heat gain coefficients are substantially lower than for other systems due to the double envelope and the ventilation of the cavity to the ambient. The overall architectural concept, engineering design and outcomes of an experimental campaign over a 2-story full scale test in Spain are presented.

Keywords: Curtain Wall, Ventilation; Solar heat; Experimentation.

1. Introduction

In the 21st century, there is an increasing awareness of scarcity of resources and the risks associated with climate change in an overpopulated planet. This has led to increasingly stringent public policies towards the use of energy, with the promotion of energy conservation and efficiency such as *EC(2010)*. As per *EC(2010.b),* as much as 40% of the total final energy use is performed in buildings. Considering increasing requirements for ventilation to compensate for more air-tight envelopes and the known issues about indoor air quality effects on human health, there is a need to match increasing energy loads in buildings due to ventilation with the aforementioned energy conservation and efficiency measures. In this context, ventilation energy loss accounts for up to 50% of space heating or cooling needs in some cases.

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Already common in the last decades, the popularity of glazed envelopes is increasing in commercial buildings, and even in some high-end residential projects. However, this popularity is met with energy performance levels not meeting energy conservation standards in some cases. Modern components such as additional glass panes, gas-filled cavities, low emissivity coatings and thermally broken framing elements have been developed to partially mitigate these problems. Recent developments in Building codes such as the Spanish *CTE (2019)* has led to U-value requirements for highly glazed buildings in the range of 0.8 W/m²K (Garay, 2020), thus Passivhaus-certified product performance levels (Passivhaus Institute, 2015). But although these products can meet energy conservation standards, there is still a need to contribute to the energy efficiency target, by means of the incorporation of renewable energy sources, and to mitigate the environmental footprint of buildings.

Also, comfort-related issues are reported by building occupants in the vicinity of glazed envelopes. Low surface temperatures in winter periods and direct solar radiation or high surface temperatures during irradiated periods and hot periods are known issues of these systems.

Considered the exposed trifold issue with energy conservation, energy efficiency and comfort, a technical solution is proposed, where a double envelope unitized curtain wall (DEUCW) is proposed to pre-heat ventilation air. This system reduces radiant asymmetries and occupant discomfort due to greater heat absorption in the glass and delivery to a ventilated cavity. The cavity is connected to the intake of and Air Handling Unit (AHU).

This paper presents the DEUCW configuration, adaptation schemes for highly glazed buildings, outcomes of a full-scale energy performance assessment, and projections of the energy savings over the full year.

2. Typical configurations of Highly Glazed Buildings

Modern multi-rise buildings generally share some common features:

- Highly glazed envelopes, yielding up to 100% in many cases
- At least partially mechanically-driven ventilation system
- Centralized HVAC systems, where ventilation systems are located. These systems are commonly located in the roof. For buildings with more than 5-7 storeys, HVAC plants are distributed across the building, with a dedicated technical floor every 5 to 7 storeys.

The DEUCW system shall be defined to adapt to this context, both in terms of architectural definition, and capacity to address the energy loads and fresh-air ventilation airflows required in such integration schemes.

Figure 1: Glazed Multi-rise building (left) and rooftop HVAC systems (right)

3. Definition of System

The DEUCW is a double envelope system, which comprises two glazing units (two envelopes). These two panes are separated by an air cavity, where air is circulated by means by forced convection. This air is then fed into the air handling unit. Considering its glazed aesthetic and modular concept, the system achieves both aesthetic and functional integration with the building.

In terms of integration with the air handling unit, this system is similar to a Transpired Solar Collector System (NREL, 2000). The cavity is used to capture solar heat and recover transmission losses from the indoor space and operates over the full façade height. The cavity is open to the exterior in its lower end (e.g. ground level) and connected to an air handling unit in its upper end (roof, or technical room). Air is vented from the lower end to the upper connection to the technical room, and heated as it rises due to solar incidence from the sun.

Both for technical rooms and roof connections, parapet-like integrations allow for a virtually non-impacting integration with the HVAC system.

A schematic of the system is depicted in Figure 2.

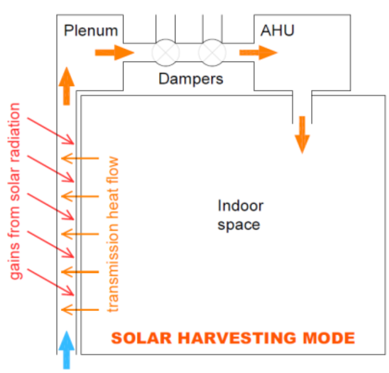

Figure 2: Schematics of system operation in solar harvesting mode

Considering the particular composition and operational scheme of the system, typical glass selection criteria has been revisited in order to maximize solar gains into the cavity, while avoiding direct solar gain into the building. A particular implementation of the system for the city of Bilbao (~40°N, ~1000 HDD/y):

- Single glazing to the external side, in order to maximize solar gains,
- Double glazing with a low-emissivity coating to the cavity side, to prevent heat loss from indoor air and deliver the solar gains within the cavity air.
- Hygienic issues are considered twofold:
    - Filters are installed at the bottom edge of the DEUCW, in a location with ease of access for cleaning, maintenance & substitution.
    - Specific panes (ca. 1/3 of the total surface) can be opened from the internal side for maintenance & cleaning activities.

The design of the system is presented with greater detail in a previous publication (Gonzalez *et al.*, 2018).

4. Experimental Assessment

A full-scale prototype was constructed and installed in a purpose-specific building in the vicinity of the KUBIK $_{\text{by Tecnalia}}$ test facility (Garay *et al.*, 2015), nearby Bilbao, Spain. A 3x2 layout was installed, where 2 modules were connected in vertical/serial arrangement, and a total of 3 cavities were generated. A total prototype area of 14.8 m^2 was installed. The DEUCW was connected to an AHU, equipped with a variable speed fan and an electric heating coil with several heating levels. The ventilation air was introduced into a 30.5 m^3 room on the ground floor, in direct contact with the DEUCW. Considering the physical setup presents a large DEUCW to volume ratio, ventilation rates were set to be representative of a much larger building. The effective ventilation rate was set at 683 m^3/h, considered to be equivalent to that of a building with a 25 m depth.

Figure 3: Test setup

An experimental campaign was initiated in June 2019, and is still ongoing. The experimental campaign has been designed to identify the performance of the system for various outdoor and indoor temperatures, and solar radiation levels. From the experimental campaign, several relevant data have been extracted and analysed (Garay-Martinez *et al.*, 2020). In terms of heat gain when the DEUCW is active, radiation-dependent temperature gains were observed in the range of 5 to 15 °C.

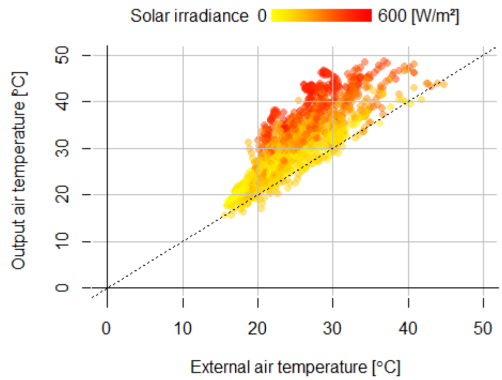

Figure 4: Inlet-outlet temperature gain in the cavity. (*Roberto Garay-Martinez et Al. (2020)*)

Based on the data from the test campaign, linear correlations were calibrated for the output power and system performance with regards to bounding temperatures and solar irradiation.

$$P = 0.304 * I + 14.54 * (Ti-Te) \quad (1)$$

$$\eta = 0.304 + 14.54 * (Ti-Te)/I \quad (2)$$

Where:

P = output power per glazed area in W/m²; I = solar irradiation in W/m²; Ti = internal air temperature; Te = external air temperature; η = system efficiency (P/I).

Greater detail of the experimental setup and assessment is provided at Garay-*Martinez et al.* (2020).

5. Climate Projections

Several projections have been perfomed to assess the performance of the DEUCW system over various climates. In all cases, Cfb climates according to the Köppen-Geiger classification (Kottek, 2006) have been taken. The following climates have been chosen: Bilbao (location of the test referenced in section 4), Auckland and Sydney (for their regional relevance). In all cases, the temperature difference (ΔT) between outdoor air and the balance point of a commercial building has been considered. A balance point of 18 °C has been considered. The ventilation air temperature rise across the DEUCW system has been calculated, and its impact in the ventilation ΔT assessed.

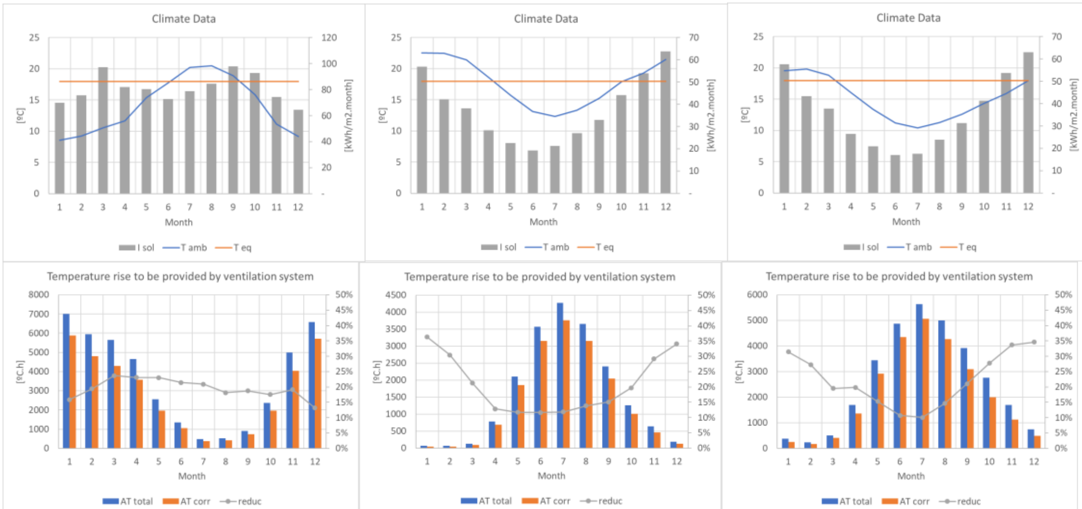

Figure 5: Climate conditions (above) and Ventilation ΔT (below) for Bilbao (left), Sydney (centre) and Auckland (right)

Depending on the location, an average ventilation load reduction in the range of 15 to 20% is achieved with the DEUCW system.

6. Discussion & Conclusions

In this paper, a novel DEUCW system is presented, together with an experimental assessment of its performance.

The DEUCW system allows for the solar energy capture and its use for the reduction of ventilation heating load in buildings. Other benefits are the reduction of transmission heat loss through the envelope, and the reduction of local discomfort in the vicinity of the glazed envelope.

The overall system concept is presented, and a full scale test prototype constructed. As an outcome of this, it can be concluded that the system is validated towards its architectural and mechanical engineering aspects.

With regard to the energy performance, the outcome of the experimental assessment provides a calibrated model, which is used to extrapolate the performance of the system to a wider scale. Actually, the experimental mock-up is already scaled-up, as its ventilation rate corresponds to that of a building with a much deeper façade-to-floor-area ratio.

Climate projections state that the system can meet in the range of 15 to 20% of the ventilation heating loads of commercial buildings.

The aforementioned assessment is by itself promising, but it should be considered as a conservative value due to a couple of facts. On one side, the capacity of the DEUCW system to virtually avoid transmission heat loss is not considered in this study. On the other side, the climate projection did not consider additional energy performance due to overheating possibilities for periods where the DEUCW system not only met, but surpassed ventilation ΔT.

Also, this paper has been focused in the performance of the DEUCW system during the heating season. This system is expected to produce also savings in cooling loads in summer mode due to the highly absorptive glass layers in a ventilated arrangements have not been considered in the calculation.

With all these considerations in mind, the authors believe that such a system should be further considered within architectural projects for commercial buildings.

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