

CERAMIC VENTILATED FAÇADE WITH WARM AIR RECOVERY

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1. ABSTRACT

"Sustainable Habitat" is a research project carried out by several technology institutes with IVACE and ERDF funding. The main aim of the project has been the design and development of solutions for improving ambient comfort with regard to thermal conditioning and light, as well as air quality, by integrating smart materials and sustainable solutions.

A key project objective, on which this paper focuses, was development of a ventilated façade system with heat recovery to enable analysis of the reductions in energy consumption on considering the internal conditions applicable to hospital use. The development process of the system comprised the following stages:

Strategy approach. To improve thermal comfort and interior air quality in winter conditions, three strategies were considered. The "TYPE 1: Recirculation" strategy was based on recirculating air inside the room through the ventilated façade cavity, as a back-up to the heating system. The "TYPE 2: Renewal" strategy consisted of pre-heating the outside air needed for interior air renewal, through its passage through the ventilated cavity. Finally, the "Reference" strategy consisted of performing the renewals by incorporating the renewal air directly from outside, keeping the temperature setting of the interior space at 21°C.

System design and definition of specifications. The characteristics were defined that ventilated façade systems must meet to allow warm air recovery from the channel (climate zones, orientation, ceramic tile colour, channel width, joints, ventilation, location of sensors and equipment, etc.).

Development of the control system. A computer program was developed to save data in log files and also to perform automatic control of the demonstrator.

Inclusion of sensors and equipment. The sensors, control system and equipment (air vents, fans) required for correct operating and monitoring of the strategies were integrated into the demonstrator.

Validation of use/functionality of the system. This consisted of monitoring and analysing the results for the different strategies involved, in order to obtain the energy consumption reduction values of the thermal conditioning system in a healthcare environment.

2. INTRODUCTION

This project has been co-funded by the IVACE and the European Regional Development Fund (ERDF), within the ERDF Operational Programme of the Valencian Community 2014-2020 in the call for grant applications aimed at Technology Centres in the Valencian Community for R&D projects. The main aim of the project has been the design and development of solutions for improving environmental comfort with regard to thermal conditioning and light, as well as air quality, by integrating sustainable solutions.

Studies conducted in the last few years¹ have shown that ventilated ceramic envelopes contribute to heat reduction in summer (lower cooling demand); however, they limit heat penetration in winter (greater heating demand). To improve ventilated façade performance in the winter period, two strategies were considered and analysed based on the development of a ventilated façade system with heat recovery.

This paper describes the procedure implemented for assessing the system and the results obtained in reducing energy consumption for both strategies in internal conditions applicable to hospital use.

3. STRATEGIES

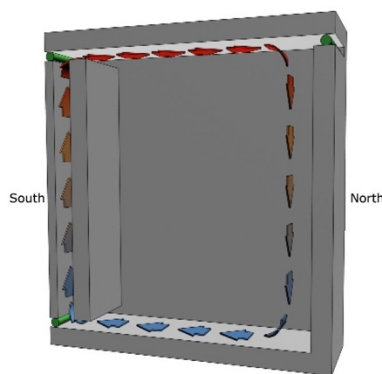
In previous studies undertaken by ITC², improvements were evidenced on developing Energy+ simulations, which stemmed from the recovery of warm air from the ventilated cavity, used as a back-up for building thermal conditioning and ventilation systems. These improvements, together with the requirements of current regulations concerning ventilation in buildings (CTE DB HS3 and RITE), suggested analysis of the contribution of these systems for improving energy efficiency in buildings.

In this project, a series of strategies were considered for using warm air from the ventilated cavity during the winter period. These strategies were implemented in a demonstrator that enabled their performance to be monitored and assessed. The strategies involved are described below:

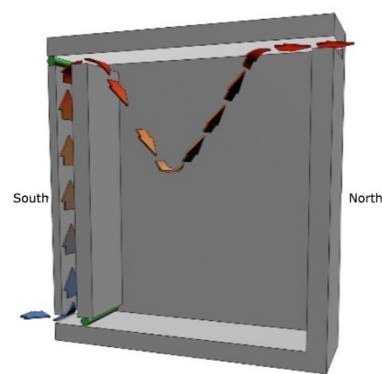
Reference strategy, hereinafter referred to as “**TYPE 0**” strategy. This consists of performing interior air renewals by incorporating the renewal air directly from outside (without using the ventilated façade). This strategy allows obtainment of reference values for comparison with the results of the two strategies set out below.

Recirculation strategy, hereinafter referred to as “**TYPE 1**” strategy. This is based on recirculating interior air from the room into the ventilated façade cavity, as a back-up to the heating system.

Renewal strategy, hereinafter referred to as “**TYPE 2**” strategy. This consists of performing the air renewals required by the regulations, by making outside air pass through the ventilated cavity, thus increasing air temperature before letting into the interior space.



TYPE 1 Strategy: Recirculation



TYPE 2 Strategy: Renovation

4. DEMONSTRATOR

To assess the strategies, the demonstrator developed within the framework of the Open habitat project³ was used. This demonstrator, with floor dimensions of 6x4.8 m and a height of 2.5 m, was located at Jaume I University to integrate the equipment and sensors to be used in controlling and monitoring the strategies.

A ventilated façade system, consisting of porcelain stoneware tiles 11 mm thick and anthracite in colour (absorptance =0.85), was installed on the demonstrator's south façade, with a surface area of 15 m². The tiles were fixed with a concealed clip system to the metal substructure fastened to the inner leaf. A series of air vents and impellers were also installed to enable the inflow and outflow of interior air to be controlled, which are described below:

- 2 air vents in the bottom part of the ventilated façade, to control the inflow of air into the ventilated cavity.
- 3 impellers in the top part of the inner leaf of the south façade, to enable forced air convection in both strategies.
- 2 air vents in the bottom part of the inner leaf of the south façade, to enable recirculation of the air in the case of type 1 strategy.
- 3 impellers in the top part of the glass of the east façade, to enable renewal air feed in "Type 0" and "Type 1" strategies, and in "Type 2" strategy, in those cases in which it was not possible to renew air through the ventilated façade.
- 2 air vents in the top part of the NORTH façade sheet of glass, to enable air outflow.



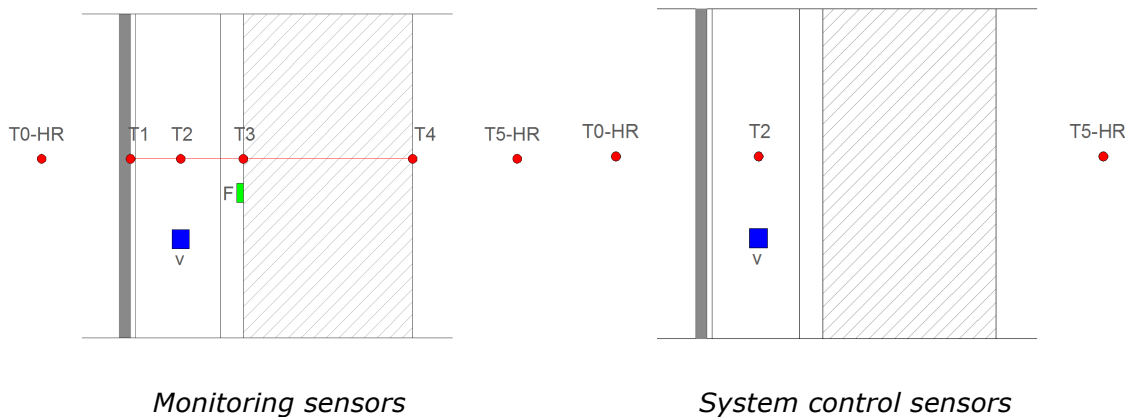
Integration of SOUTH ventilated façade



Vent integration in NORTH ventilated façade

To monitor the strategies, a pyranometer for measuring solar radiation was installed on the roof of the demonstrator, in addition to a series of sensors to measure temperature, relative humidity and air speed both at the ventilated façade and inside the demonstrator.

The location of the sensors required for measuring the parameters to validate performance of the ventilated façade system is defined in the figure on the left. The sensors enabling system control as a function of the defined strategy are shown in the figure on the right.



Nomenclature:

- Outside conditions. Temperature and Relative Humidity (T0-RH)
- Internal tile temperature (T1)
- Air temperature in the ventilated cavity (T2)
- Temperature of the outer and inner surfaces of the bearing wall (T3 and T4)
- Heat flow through the bearing wall (F)
- Air speed sensor (V)
- Interior conditions. Temperature and Relative Humidity (T5-RH)

5. DESIGN SETTINGS

The assessment of the ventilated façade system with warm air recovery was performed in accordance with the requirements for air renewal in healthcare environments. The internal conditions applicable to healthcare environments in accordance with current regulations are set out below.

5.1. TEMPERATURES

A temperature setting “ T_c ” of 21°C in accordance with the recommendations of the UNE-EN ISO 7730 standard for healthcare environments was used. Thermal-conditioning equipment was installed (heat pump) to control the set temperature inside the space.

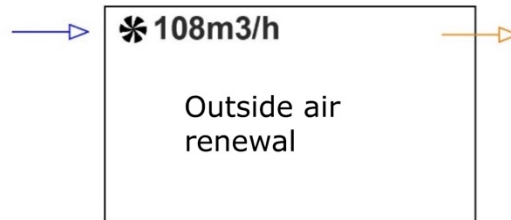
5.2. AIR RENEWAL

Air renewals for the demonstrator of 108 m³/h were considered, in accordance with the calculations made based on the DBSI and RITE IDA1 requirements for an “inpatients treatment zone” in hospital use.

5.3. CONTROL SYSTEM REGULATIONS

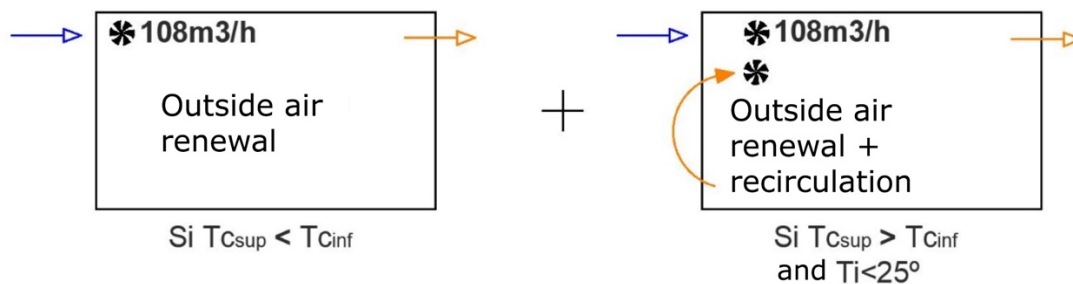
Based on these conditions, the design settings and programming of the control system were defined for each of the strategies:

- **"TYPE 0" strategy.** In this case, the inflow of renewal air occurred directly from outside, through the fans located in the EAST façade, keeping the interior temperature setting at 21°C.



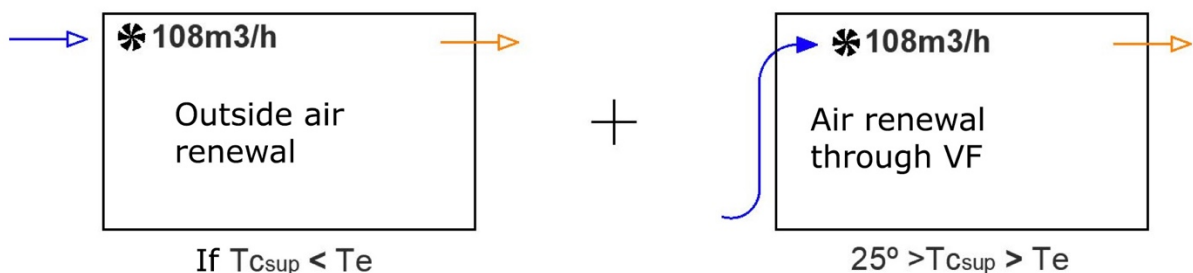
Operating diagram. TYPE 0 strategy

"TYPE 1" strategy. The air recirculation system through the ventilated façade was started when the air temperature in the top part of the channel of the ventilated façade "TCsup" was higher than the interior temperature "Ti" of the demonstrator. The system thus recirculated interior air from the room through the ventilated channel, increasing the air temperature and acting as a back-up for the thermal conditioning system. In this case, the air renewals were performed by incorporating air directly from the outside.



Operating diagram. TYPE 1 strategy

Type 2 strategy. This consisted of performing the interior air renewals by using the warm air that was generated in the ventilated façade channel. When the air temperature in the top part of the ventilated façade channel "TCsup" was higher than the outside air temperature "Te", the air renewals are performed through the ventilated façade. However, when this rule was not obeyed, the renewals were performed by incorporating air directly from outside.



Operating diagram. Type 2 strategy

On the other hand, to reduce the number of fan and air vent start-ups linked to the Type 1 and Type 2 strategies and to prolong their durability, it was determined that both strategies would start running whenever the sun radiation value recorded by the pyranometer was greater than 100W/m², thus avoiding possible equipment start-ups early in the morning or late in the day and during the night.

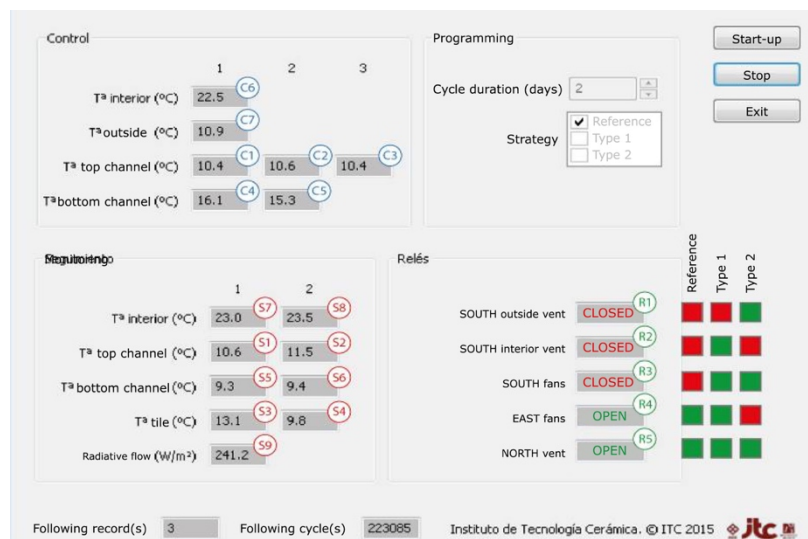
6. MONITORING

The strategies were monitored for a period of 4 months, from December 2015 to March 2016. During this time, measurements were made of each of the strategies on independent days, in order to compare the results with similar outdoor conditions.

Data acquisition and control of the strategies were conducted using the computer program developed by ITC. The data acquisition system developed was based on a series of ADAM 6000 modules, which enable a series of variables to be recorded simultaneously and, depending on the values recorded, a series of decisions to be taken which can be reported to the system via a set of actuators triggered by relays.

The computer program was developed using C++ language and was responsible for keeping the data in log files and also for automatic control of the prototype. The program has a graphic interface which allows display of the values of the recorded variables in real time, observation of the state of the various relays which are being acted upon and enables simple programming of how the studied control strategies are to alternate.

The first figure shows the graphic interface of the control program, while the second figure displays the location of the sensors on the ventilated façade (*C1 to C7 control thermocouples; S1 to S8 monitoring thermocouples; S9 pyranometer*).



Control program interface



Ventilated façade sensors

7. VALIDATION

Validation of the strategies proposed was considered from two points of view: on the one hand with regard to user comfort and, on the other, to the functionality of the strategies considered. This validation sought to show that the proposed strategies met the following objectives:

- Increase in energy efficiency (reduction in thermal conditioning energy consumption).
- No decrease in comfort in the interior space.

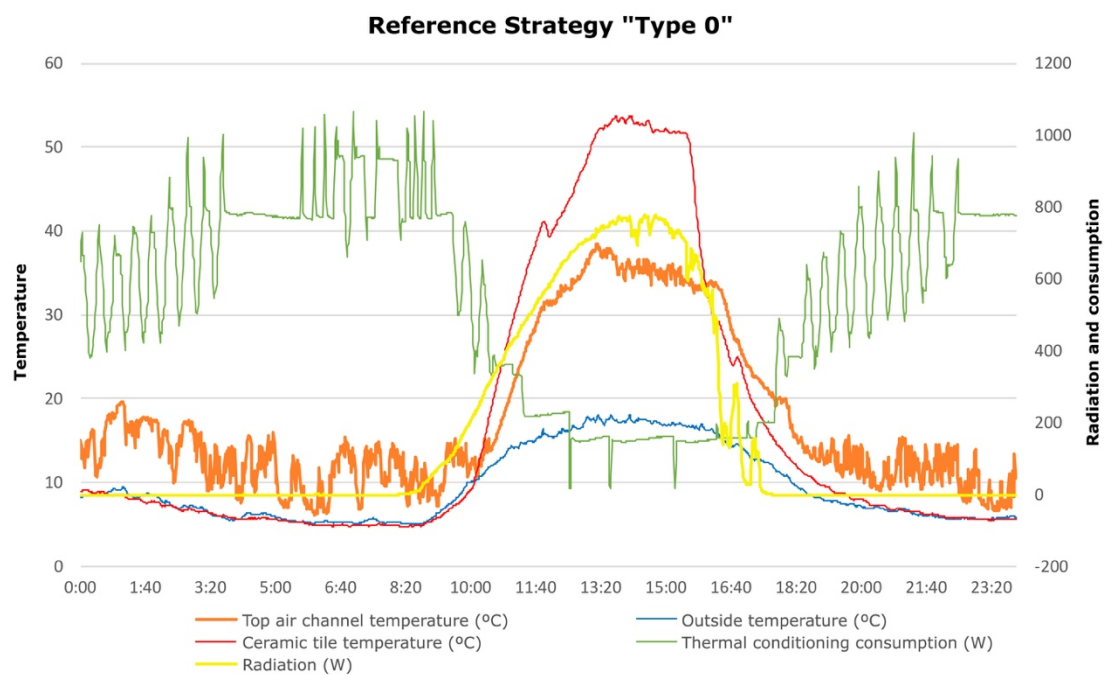
7.1. COMFORT VALIDATION

To validate this, on the one hand, an objective measurement of temperature, relative humidity, radiant temperature and air speed at six points in the demonstrator was made using an "air tree" after applying the three different air renewal strategies. On the other hand, through a user panel, subjective comfort was measured. In the results obtained using these tools, no discomfort was detected in strategies 1 and 2.

7.2. FUNCTIONALITY VALIDATION

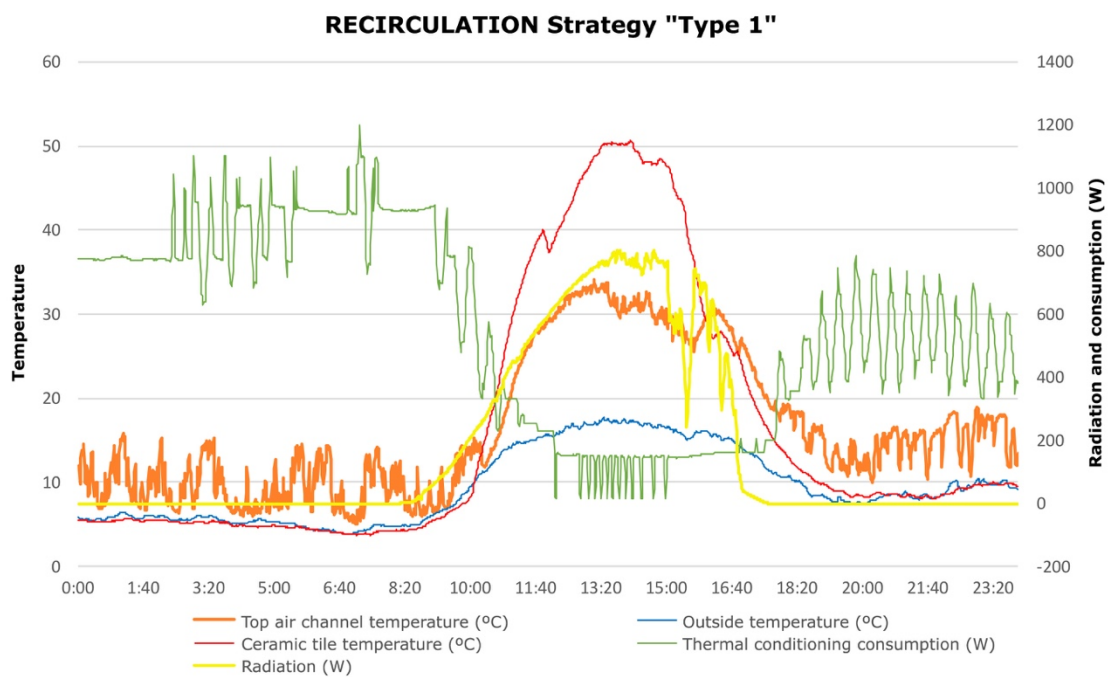
To validate the functionality of the system, the data obtained for the different strategies (Reference, Type 1 and Type 2) were monitored and analysed, and the contribution of the strategies to the reduction in energy consumption of the thermal conditioning equipment was obtained by installing an energy consumption meter. The following graphs show the performance of each of the strategies on plotting the most relevant data taken throughout the day under similar conditions.

In the case of the reference strategy, it was noted that the temperature of the ceramic tile exceeded 50°C in the central hours of the day, and values close to 40°C were obtained from the air temperature in the ventilated cavity channel.



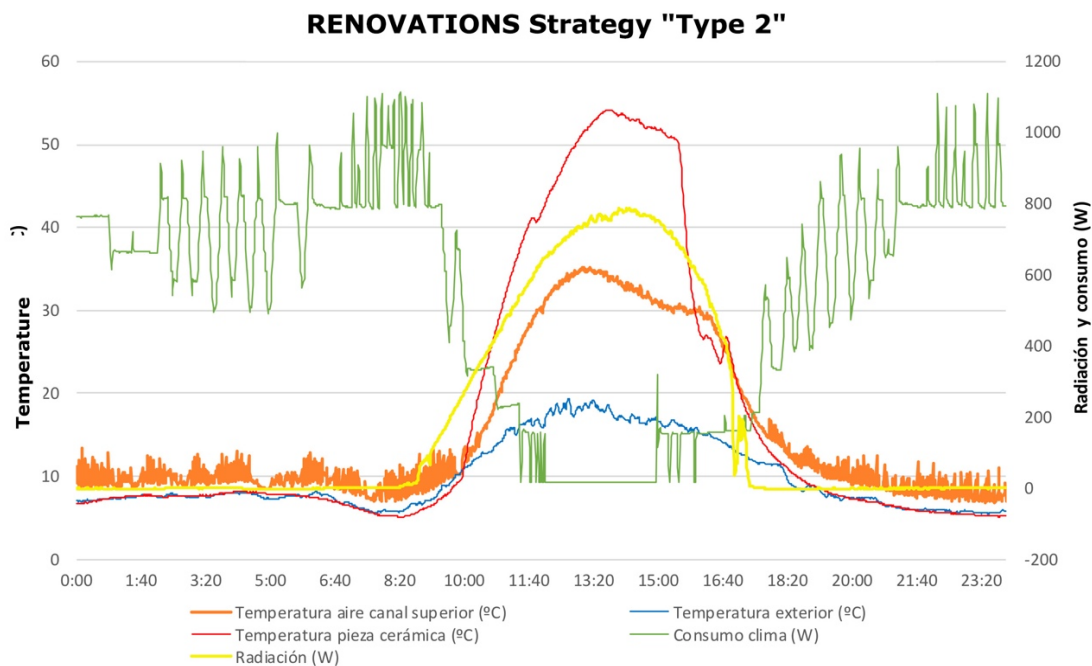
Daily performance. Reference strategy

In the case of the TYPE 1 strategy, a point reduction of consumption in the thermal conditioning equipment was observed during the central hours of the day.



Daily performance. TYPE 1 strategy

The data obtained for the TYPE 2 strategy show how the air temperature in the channel was slightly lower than that obtained in the reference strategy, reaching maximum values of 35°C in the central hours of the day, due to the fact that the air in the cavity was being fed into the interior of the demonstrator as renewal air, thus contributing to the reduction in energy consumption of the thermal conditioning equipment in heating.

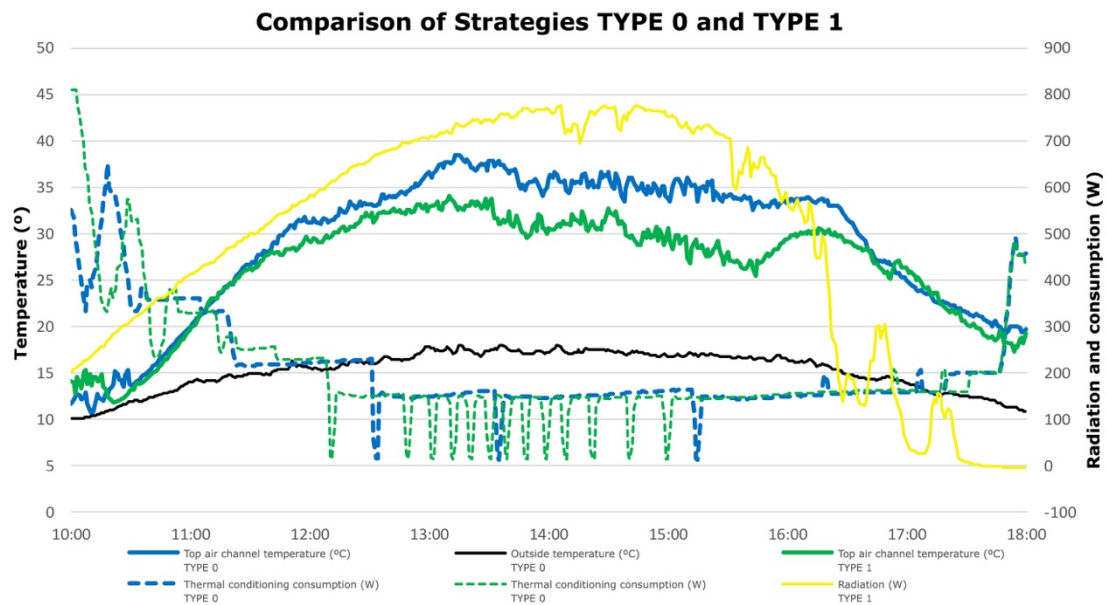


Daily performance. TYPE 2 strategy

Once the strategies had been analysed individually, a comparative analysis of strategy performance was conducted. To do so, the days considered were those on which the following conditions were found, between 10:00h and 17:00h:

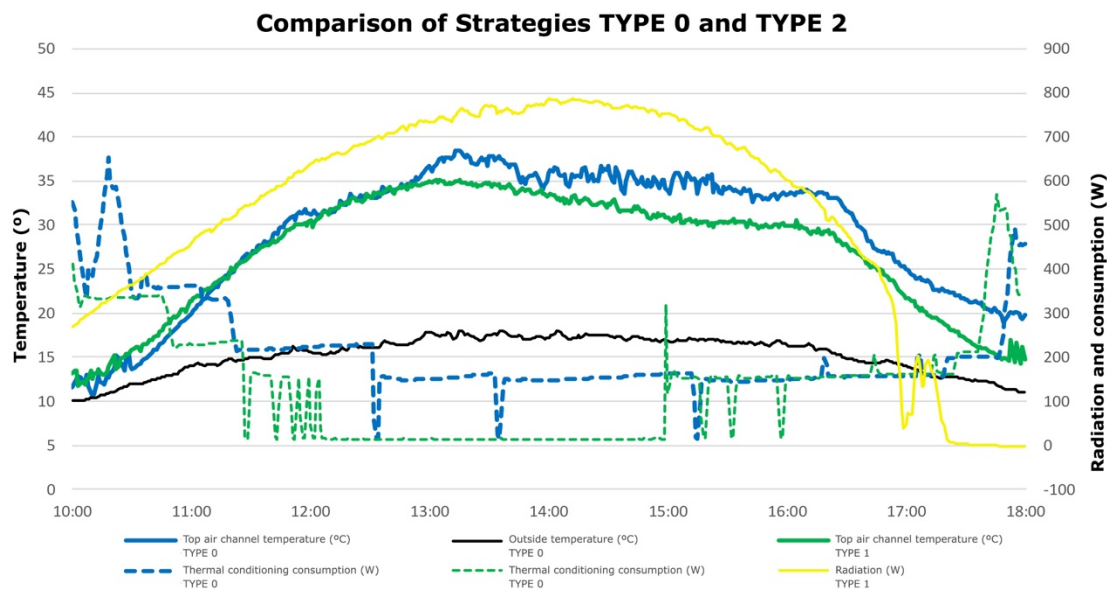
- Sunny days, with an average radiation between 560W/m² and 720W/m²
- Average outside temperature between 15 and 16°C

First, the comparison between TYPE 0 and TYPE 1 strategy is shown.



As can be seen, during the central hours of the day, between 12:00 and 15:00, the thermal conditioning equipment made point shut-downs, due to the fact that air recirculation through the ventilated channel was sufficient to hold the 21°C temperature setting. In this case, the TYPE 1 strategy enabled reduction in energy consumption of about 5%.

Secondly, the comparison between TYPE 0 and TYPE 2 is shown.



On comparing the experimental results, it can be seen that, during the central hours of the day, the thermal conditioning equipment shut down completely, as the pre-heated air which was fed through the ventilated façade to perform the air renewals was sufficient to keep the interior temperature setting in the room. In this case, a reduction in energy consumption of about 40% was achieved.

8. CONCLUSIONS

The analysis of these data under similar conditions for the three strategies considered yielded the following results:

- In the **TYPE 1 strategy**, between 5 and 20% reductions in energy consumption of the thermal conditioning system were obtained, compared to the reference strategy under similar conditions.
- In the **TYPE 2 strategy**, between 15 and 40% savings in energy consumption of the thermal conditioning system were achieved, compared to the results obtained in the reference strategy on days with similar conditions.
- No **discomfort was detected** with strategies 1 and 2.

Therefore, the two strategies envisaged with the warm air recovery system in the cavity can contribute to obtaining important savings in thermal conditioning energy consumption in healthcare environments; however, these strategies may be extrapolated to buildings with other uses, such as residential use, in which significant reductions in energy consumptions could be achieved.

Another aspect to be taken into account is that during the monitoring period, higher than expected outside temperatures were reached for a winter period since, according to data from the Spanish National Meteorological Agency (Aemet) up to 30 November, the average temperature was around 16.5°C, 0.8°C more than the average value for the period 1981-2010, thus making this, according to Aemet, the "fourth warmest year in the historical series". For this reason, in lower temperature conditions, in line with the winter period or in cold climates, the performance of the different strategies considered may be expected to reach significant improvements.