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NATURWALL© - A solar timber façade system for building refurbishment: optimization process through in field measurements

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Abstract

Building renovation is one of the key issues of recent European policies towards energy efficiency. The concept of an opaque, modular and prefabricated vertical façade, made of wood and lightweight components, is proposed in this framework. Naturwall© is an Italian patented project intended for the retrofitting of existing buildings, to improve both the energy performance of the building and its architectural aspect. Different prototypes of the façade were tested during an experimental campaign carried out in outdoor test cells. The here presented results describe the winter and summer behavior of the façade through the use of synthetic indexes i.e. the U-value and pre-heating efficiency.

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Keywords: Retrofit system; wood technology, solar active façade, experimental campaign, prefabricated façade.

1. Introduction

Cities currently play a vital role in the quest for global ecological sustainability, and they represent an opportunity to drastically reduce the environmental costs associated with climate changes. Buildings contribute to carbon emissions to a great extent, and they can either contribute to environmental depletion or be a source of ecological rejuvenation, depending on how urban centres are managed [1]. The renovation of old buildings is actually a challenge that requires increased efforts in order to reduce global climate changes, by channelling more investments

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and awareness in this sense, by defining more experimentations and by finding innovative solutions [2]. The difficulty of carrying out interventions on existing buildings arises from the lack of information on the existing structure and the lack of coordinated processes. Due to the multidisciplinary skills involved, as well as for the concerns related to the process of optimisation, working on renovation is more competitive than working on the new construction.

The aim of achieving noticeable energy saving in buildings is a complex process, especially if the buildings are very old. It has been shown in the latest Buildings Performance Institute Europe (BPIE) report, pertaining to the situation of the building sector in Europe, that old constructions are characterized by the worse energy saving potential [3].

The refurbishment of buildings currently seems to be the best way of tackling climate changes, even more so than some years ago. The amount of energy consumed by the built environment is about 40% of the total energy consumed; households in Europe are responsible for 27% of the overall energy consumption (Eurostat, 2011). The EPDB (Energy Performance of Buildings Directive, 2002/91/EC) sets the European approach to reduce the energy demand. The new legislation is focused on moving towards new and retrofitted nearly-zero energy buildings by 2020 (2018 in the case of public buildings), and the application of a cost-optimal methodology to set the minimum requirements for both the envelope and the technical systems.

A substantial share of the stock in Europe is older than 50 years, with many buildings in use today that are hundreds of years old. More than 40% of our residential buildings were constructed before the 1960s when energy regulations were very limited. The countries with the largest components of older buildings include the UK, Denmark, Sweden, France, the Czech Republic and Bulgaria. A large boom in construction took place between the sixties and nineties and the housing stock, with a few exceptions in certain countries, more than doubled [4].

Harvesting renovation opportunities could be a real benefit for Europe economies and society. Some economics studies [5] pointed out that efficiency offers an enormous "win-win" opportunity. This approach refers to the externalities, such as harm to human health, climate changes, and constraints on the foreign policy objectives of energy-importing countries, that could be amplify with correct investments in energy efficiency. The Naturwall façade project was conceived in this context.

2. The NATURWALL façade

1.1. The Naturwall Façade system

Naturwall© is a patented project, which was developed in the frame of a research conducted by the Department of Architecture (DAD), and which then became a spin off project – be-eco - of I3P - Innovative Enterprise Incubator. The building component is an innovative energy efficient system for façades that was specifically developed for the refurbishment of existing buildings. The module is prefabricated and it is made of wood-based materials. The project had the objective of introducing an industrialized design method into the renovation of the existing built environment to exploit the opportunities given by "off-site" production and the parametric design approach, without neglecting the aesthetical values or the possibility of changing the architectural image of residential and non residential constructions. The target of the Naturwall method is primarily that of improving building energy efficiency and, as a direct consequence, of reducing GHG emissions. Energy efficiency poses special demands on the quality and performance capabilities of a facade envelope, although, in the field of renovation and refurbishment, high energy retrofitting results and greenhouse gas reductions could be achieved through the use of multifunctional facade systems [5,6]. Smart façade solutions, in which the surface of a building envelope is used as an "active skin", are being adopted more and more frequently, as can be seen from the advances that have been made in this sector and from the solution yet available in the market (GAP system, TES Energy Façade, etc..), and in particular those pertaining to new advanced solutions that exploit façade integrated ventilation. The aim of this project was to take advantage of the opportunity offered by the use of industrialized systems in the retrofitting of urban spaces. In this context, especially in really dense urban areas, it is important to define a strategy that considers the operative conditions and a reduction of the time cost of the retrofitting operations. One of the purposes of this research is to connect the design phase to the construction phase, identifying the instruments that are necessary for controlling and managing the overall process, concurrently evaluating, from the early design phase, all the risks, the financial issues and pay-back return periods.

1.2. The Naturwall façade concept

The so far conceived and tested module is composed of natural and low-cost materials, such as wood and cardboard, and it has a wood structure and assembly made up of an external stratified glazing (3+3 mm), a natural ventilated cavity (40 mm) with a honeycomb cardboard material (30 mm), and an insulated sandwich panel (98.9 mm). The Naturwall module can be positioned in the existing envelope between structural beams fixed onto the floors.

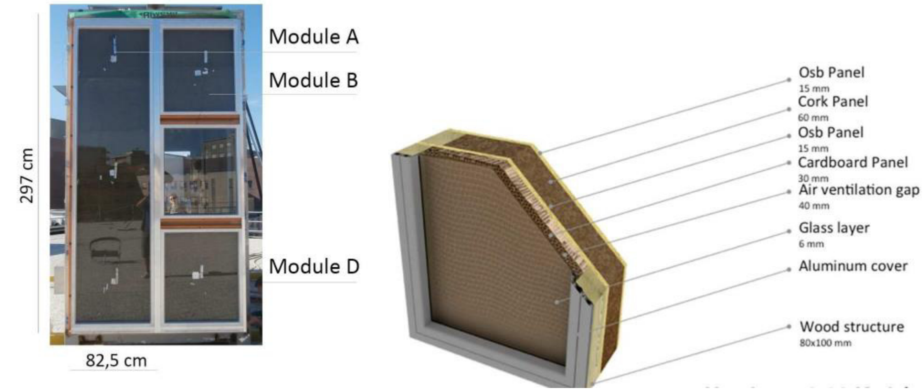

Fig. 1. (a) Naturwall mounted onto the TWINS test facility at the Politecnico di Torino; (b) Schematic section of the system.

The façade concept starts from an adaptive building skin approach which is aimed at reducing the heat flow that crosses the façade under different boundary conditions. During winter, the building envelope is used as a solar collector; it exploits the solar radiation that strikes on the glazing, and which is collected by the honeycomb structure. The cardboard panel was applied into the system in order to optimize the solar heat gain and to make the solar rays impinge the surface of the system. The shape of the honeycomb was defined to maximize the solar heat gains during winter and to offer shade from summer solar radiation. Furthermore, the component, thanks to its shape, is able to reduce the transfer of convective heat. In the cooling season, the solar heat is partially removed, by means of natural driven ventilation in the cavity, to prevent overheating.

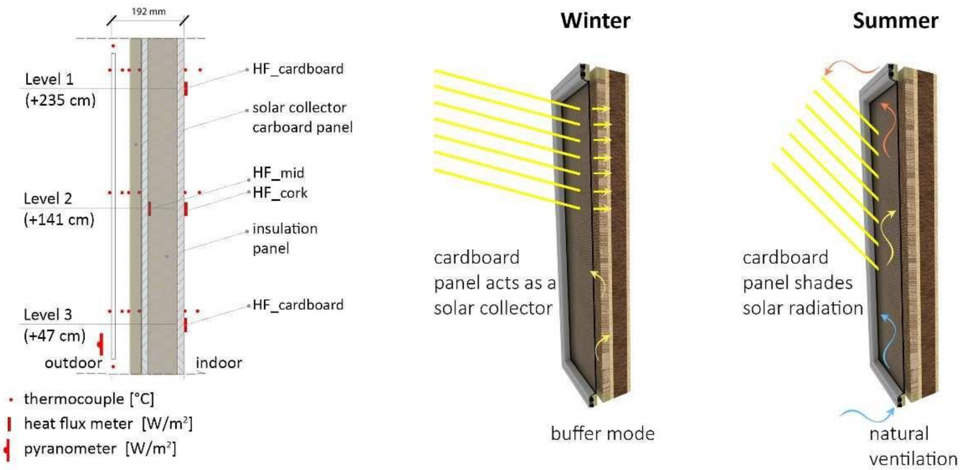

Fig. 2. (a) Schematic view of the façade, position of the sensors (left). (b) Functioning strategies for the different seasons (right).

3. The experimental campaign and the measurement apparatus

An experimental campaign was set up to characterize the thermal performance of the Naturwall façade. The façade was installed on an outdoor test cell (TWINS facility), located on the rooftop of the Dept. of Energy at the Politecnico di Torino. The experimental campaign was planned to evaluate the façade performance throughout different seasons, in order to verify the dynamic behavior of the system. The monitoring activity was aimed at optimizing the façade configuration, thus different modules of the façade were tested in parallel, as can be seen in figure 1a. Modules A, B and D differ in dimensions and in the insulation material applied to the internal side. Module A is a 1:1 sample of the tested system (82.5x297 cm), while modules B and D have smaller dimensions (82.5x86 cm). During the winter season, two different insulation materials were tested on façade module A, level 2. The 8 cm cardboard panel was substituted with a dark cork panel of the same depth. The cardboard panel has a thermal conductivity value of 0.095 W/mK, measured in the laboratory using a heat flow meter apparatus. During the summer season, the system was tested with the air cavity being naturally ventilated and with cardboard insulation, while the air cavity was tested during the heating seasons in both buffer mode and ventilated mode. The monitoring campaign was aimed at investigating four different aspects of the façade performance:

- the effectiveness of the natural ventilated air cavity,
- the shading and the storage efficiency of the cardboard panel,
- the insulation properties of different materials (cardboard and cork panels),
- the overall thermal performance of the system.

Continuous measurements were carried out over nine months (from July 2014 onwards) and they are still ongoing. The thermal measurements were conducted by means of thermocouples and heat flux meters that had previously been tested and verified in the laboratory. The boundary conditions i.e. the incident solar radiation and air temperatures, were also monitored. The sensors were connected to a data logger and they registered data every 15 minutes. The instruments were applied to three different levels of module A to evaluate the stratification of the temperature at different heights. Micro-fan ventilated thermocouples were introduced to register the air temperature in the cavity.

4. Results and discussion

Data analyses were conducted, during both the cooling and heating season, to evaluate the façade thermal behaviour. The equivalent thermal conductance and transmittance were evaluated according to ISO 9869/ 2014, with the progressive average methodology (equation 1), as the average values of the specific heat flux and surface temperature differences or air temperature [7]. The effectiveness of the ventilated cavity was evaluated using the pre-heating coefficient η (equation 2) [7,8].

$$C^* = \frac{\bar{\dot{q}}}{\Delta \bar{t}_s} \quad or \quad U^* = \frac{\bar{\dot{q}}}{\Delta \bar{t}} \qquad (1) \qquad\qquad \eta = \frac{t_{exh} - t_{inlet}}{t_{in} - t_e} \qquad (2)$$

where the numerator is the difference between the air temperature at the exhaust of the façade cavity t_{exh} [°C] and the air temperature at the inlet of the façade cavity t_{inlet} [°C], and the denominator is given by the difference between the indoor air temperature t_{in} [°C] and the outdoor air temperature t_e [°C]. From a physical point of view, this index represents the ratio of the enthalpy flux, related to the air in the ventilated cavity, to the enthalpy flux necessary to heat the air for ventilation purposes. The pre-heating efficiency was calculated during the days in the winter season in the buffer mode and with the ventilated cavity. For pre-heating efficiency values greater than 100%, t_{exh} is higher than the indoor air temperature, and the façade would be able to fully compensate for the ventilation loss –although transmission heat loss may occur. During summer, attention was paid to peak condition days in order to evaluate the technology performance behaviour.

4.1. Naturwall winter behaviour

The thermal transmittance and conductance calculated with the air vent closed (buffer mode) and with the cavity naturally ventilated are evaluated in Table 1. As expected, it is possible to notice that the buffer mode improves the thermal performance of the façade. All the values of U* and C* calculated for the buffer mode are in fact lower than the values for the ventilated cavity configuration. Furthermore, it is possible to notice that the lower conductivity of the cork panel than the cardboard panel improves the thermal resistance of the façade.

The pre-heating efficiency of the Naturwall façade with ventilation on and in buffer mode is reported in Figure 3. It is possible to notice that the difference between the two configurations is very small. In addition, the façade acts slightly better in buffer mode, as shown by the higher cumulative frequency when the efficiency is greater than 100% (i.e. the ventilation heat losses could be fully compensated for by the air in the ventilated façade).

During sunny winter days, it was possible to notice that the surface temperature of the cardboard panel was always slightly lower than the surface temperature between the panel and the OSB (figures 1 and 2), which demonstrates that the cardboard panel is able to act a solar collector.

Table 1. Equivalent thermal conductance (C*) and transmittance (U*).

	U* (cork) [W/m²K]	C* (cork) [W/m²K]	U* (cardboard) [W/m²K]	C* (cardboard) [W/m²K]
Buffer mode	0.16	0.24	0.24	0.52
Ventilated cavity	0.18	0.35	0.29	0.58

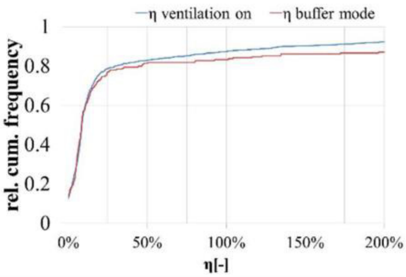

Fig. 3.Pre-heating efficiency for buffer mode and ventilated cavity.

4.2. Naturwall summer behaviour

As far as the summer behaviour is concerned, the monitoring activity was aimed at evaluating whether the solar radiation crossing the façade was partially shaded through the honeycomb cardboard and to assess the effectiveness of the natural ventilation in removing the solar heat, in order to assess whether the potential risk of overheating could be avoided.

The air temperature of the cavity in module A is shown in figure 4 a) for three different levels of the façade during a typical summer day. The peak condition is registered at 13:00, and the air temperatures at level 2 (+1.40 m) and 3 (+2.40m) are similar, while the difference between level 1 and 3 is 21.8°C. It is possible to state that the ventilation rate is effective in reducing the solar heat gain in the cavity, but only in the lower part of the façade. As the ventilation rate in the cavity is related to the height of the façade, the air cavity temperature measured in module A was compared with the air cavity temperature in modules B and D. During the selected summer days, the ventilation rate was not activated in modules B and D. In fact, an air cavity temperature value was registered at level 1 of module A that was 13°C lower than the ones measured in modules B and D. In the optimization of the façade, the air vent dimension should be larger than 40 cm^2 to enhance the stack effect and to improve the capability of removing solar heat. The internal surface temperature recorded during the summer season in peak conditions was about 30°C. This temperature, although quite high for an opaque component, does not imply thermal discomfort condition due to radiant asymmetry. It is possible to notice that if the ventilation rate were higher, the effectiveness of the ventilation would be improved and the air cavity temperature would be lower as would the internal surface temperature. The heat fluxes measured during a summer day with high solar radiation are reported in figure 4 b). In agreement with the results given in table 1, the cork panel presents lower heat fluxes than the cardboard panel. However, it is interesting to point out that the external cardboard panel is able to reduce the entering heat fluxes by 5 W/m^2 (HF_cardboard), and to shift the heat fluxes transmitted through the envelope.

Finally, the ability of the honeycomb to shade the solar radiation with a high elevation angle (summer season) was evaluated. The results have shown that the cardboard panel only acts as a solar shading during summer at level 1, while the air temperature in the cavity at levels 2 and 3 reaches such high values that they become the predominant driving force in the cavity. On the contrary, during autumn, the solar collector guides the sun rays, and the surface temperature behind the panel is higher than the external temperature.

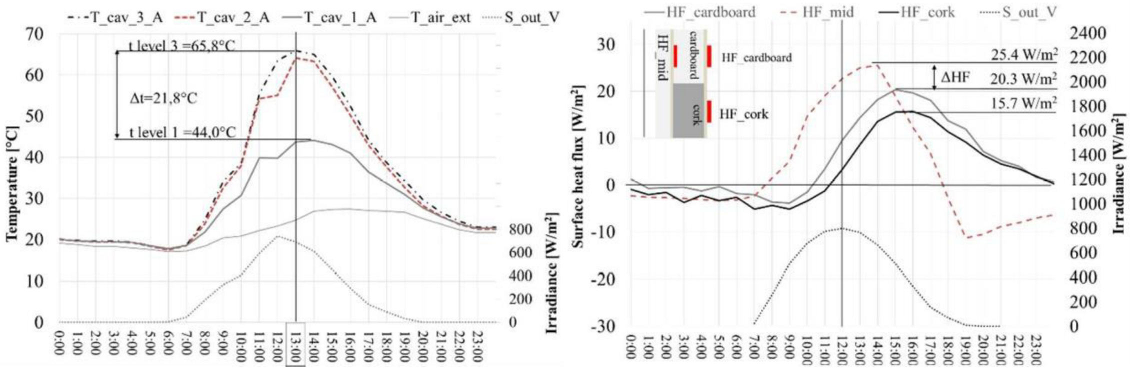

Fig. 4 Two representative summer days. (a) Air cavity temperature at different levels (left). (b) Surface heat fluxes (right).

5. Conclusions

The concept of a modular prefabricated active façade, called Naturwall©, which could be used in energy refurbishment projects, has been presented in this paper. Data concerning its energy behavior, gathered through an extensive experimental campaign carried out in outdoor test cells, have been critically analyzed and some optimization criteria have been defined. The results have shown that the façade presents a good level of insulation during winter, with low values of equivalent thermal transmittance. The pre-heating efficiency of the cavity has highlighted the potential of the façade to be integrated with a mechanical ventilation system for heat recovery. During the cooling season, the façade should be ventilated in order to improve solar heat removal.

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