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# Comparison of theoretical heat transfer model with results from experimental monitoring installed in a refurbishment with ventilated facade

**Belén Zurro García<sup>1</sup>, Beñat Arregi Goikolea<sup>2</sup>, José Manuel González Martín<sup>1</sup>, José L. Hernández García<sup>3</sup>**

<sup>1</sup> GITECA Investigation Group, University of Burgos, Spain

<sup>2</sup> Building Technologies Division, Tecnalia, Spain

<sup>3</sup> Smart Cities and Sustainability – Energy Division, Cartif, Spain

Email: bzurro@ubu.es

**Abstract.** One of the main points to consider when a building is renovated is the improvement of its energy efficiency, minimizing the heat loss through the enclosures and its heating consumption. Under this scope idea a ventilated facade was designed and incorporated in an educational building located in the city of Burgos (Spain). The main objective of this document is a comparison between the theoretical model of heat transfer across the building envelope separating the environment and the interior space, and the heat intake through a linear regression model with installed experimental monitoring. For this it has been necessary to carry out an exhaustive study of the thermal transmission of each one of the materials that make up the thermal envelope of the building, as well as the linear thermal bridges that can be produced before and after the renovation. In addition, thanks to the monitoring installed in the demonstrator building, the interior and exterior temperatures and the heat consumption of each of the radiators is known. In this way expected and real energy savings have been compared.

## 1. Introduction

The European building stock presents a high percentage of buildings constructed in the 60s and 70s, which were carried out without any consideration in terms of insulation or energy savings. The most common characteristics among these buildings are the great heat losses and the high energy demand, both electric and heating.

Public buildings represent up to 60% of the total energy consumption of the municipalities, therefore, the City Councils and other institutions at the national and international level, are committed to projects that aim to develop solutions for the reduction of this energy consumption, concentrating efforts and research in the creation or renovation of almost zero energy buildings. [8]

Among the above is the E2Vent research project "Energy Efficient Ventiladed Facades for Optimal Adaptability in the Refurbishment of Buildings" framed in the Horizon2020 strategy and financed by the European Commission. [7] This study focuses on the renovation of existing buildings of any use by incorporating a ventilated facade system. For the validation of the developed systems, two demonstration buildings were executed in two different climates, in which, in addition to the renovation actions, a monitoring system that allows the measurement of temperature and air quality was also installed.

One of the main objectives of this project is the reduction of heat losses through the enclosures of the property. This document is intended to demonstrate the thermal performance of the solution adopted,



comparing the theoretical model of heat transfer in walls, in the envelope and the global in the interior space with the experimental monitoring installed.

### *1.1. Situation of the demo building*

In November 2017, the renovation of the demonstration building was carried out in the Building 3 of the Faculty of Nursing and Health Sciences of the University of Burgos (former Military Hospital), located in the city of Burgos, in Spain, with a moderate continental climate.

This building, built in 1880, is used for teaching purposes and consists of a single floor with an area of 545.49 m<sup>2</sup>, composed of five classrooms and two bathrooms, connected by a longitudinal corridor. The main facades of the building are oriented north and south. The assessed solution was installed only in the two classrooms located at the west end of the building.

### *1.2. Original state*

The classroom is, in general, in good condition. It has load-bearing masonry walls of approximately 62 cm wide, which present certain irregularities due to the different shape of the pieces that form the facades. The union of the masonry was made with lime-cement mortar. These walls do not have any type of thermal insulation. Note the existence of double windows with wood frames and simple glazing.

The building comprises a suspended floor above a ventilated underfloor space. The supporting structure of the roof is formed with trusses made of wood and steel, on which wood purlins are also supported. The waterproofing is formed by wooden boards and flat ceramic tiles. In the classrooms there is a suspended ceiling with removable plates, which serves as a support for thermal insulation made of 8 cm thick mineral wool panels. This insulation was placed in one of the renovations that the building has seen throughout its years of use.

Regarding generation of heat energy, the building has two diesel boilers of 145 kW, which supply heat through two independent circuits, both to Building 3, which is the object of study of the present paper, and to Building 2, in which another European project is being developed. The lighting of the entire pavilion is made by 2x32W fluorescent lamps and there is a protection box at the entrance.

## **2. Refurbishment and monitoring**

The renovation works of the building began with the redefinition of the facade, marking the position of the five rows of anchors to be placed on the external surface. Subsequently, and in the delimited position, the necessary L-shaped brackets were placed to support the vertical profiles.



**Figure 1.** Metal brackets for fixing vertical profiles.

Thermal insulation was installed on the outside, consisting of two layers of mineral wool with thickness of 7,5 cm, making a total of 15 cm. These layers were fixed to the wall mechanically using fasteners.



**Figure 2.** Installation of thermal insulation.

The next step in the execution of the renovation was the placement and plumb of the vertical profiles. These profiles were fixed to the previously installed brackets, firstly through their dovetail and later with screws.



**Figure 3.** Placement and plumb of the vertical profiles.

Finally, the final cladding of the façade, consisting of aluminum composite panels, was placed. Horizontal and vertical gaps with a width of 15 mm joint were left between the panels.



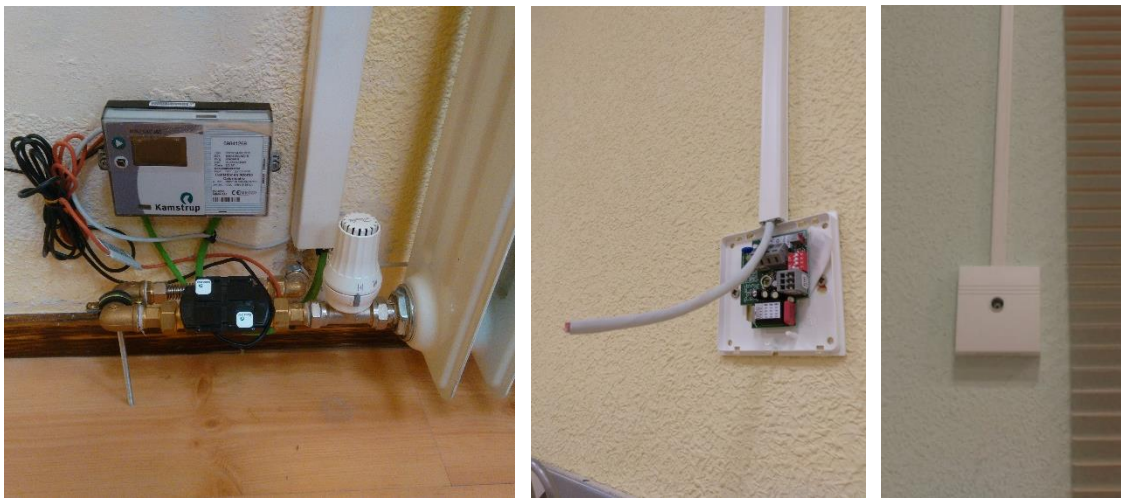
**Figure 4.** Final cladding placement.



In addition to the actions on the façade, the project considers the replacement of the existing window frames due to their low performance in terms of energy efficiency. During the work the interior windows were maintained, while the exterior ones were removed and substituted by PVC frame windows with double glazing.

As mentioned, as part of the project, an advanced monitoring system was also installed, with multifunctional systems that monitor the environmental conditions both inside and outside. Among the data obtained are indoor and outdoor temperatures, relative humidity and CO<sub>2</sub> content [13], among others. The first of these is the most relevant for this study.

In addition, flow meters were also placed in the boilers for the control and regulation of the heating and the set point temperature.



**Figure 5.** Installed monitoring devices.

### 3. Theoretical model

The present section is aimed at assessing the effectiveness of the solution implemented in terms of energy savings thanks to the reduction of heat flow through the enclosures, including thermal bridges. [11]

To calculate the heat energy flow through the opaque elements of the building envelope (walls, floors and roofs), it is necessary to know their thermal transmittance as a function of the the resistances of each of the materials that compose them.

**Table 1.** Thermal conductivity and resistance of the materials of the envelope.

	<b>Materials</b>	<b><math>\lambda</math> (W/mK)</b>	<b><math>e</math> (m)</b>	<b><math>R</math> (m<sup>2</sup>K/W)</b>
Wall	Plastering cement mortar	0.40	0.025	0.0625
	Masonry wall	1.70	0.62	0.3647
	Mineral wool insulation	0.039	0.15	3.5897
Ground	Compression layer	0.79	0.05	0.0633
	Reinforced concrete slab with infill tiles	2.00	0.30	0.15
	Cement mortar	0.80	0.05	0.0625
	Ceramic tiles	1.00	0.0125	0.0125
Roof	Plasterboard	0.25	0.0125	0.05
	Mineral wool insulation	0.039	0.08	2.05

Applying the calculation methods established by the UNE-EN ISO 6946:2012 standard [1] and following the conventions regarding the interior and exterior surface resistance marked by CTE-DB-HE-1 [2], the thermal transmittances of the different enclosures that make up the thermal envelope of the object building have been calculated.

The windows are one of the areas with greatest potential heat loss, for this, they must be considered in the calculations. As in the case of the previous planar elements, their thermal transmittance must be obtained. For this, the calculation method established in the ISO 10077-1:2017 standard [3] is used.

Once the transmittances are calculated, the thermal bridges that could have been left after the renovation are studied, by using the THERM 7.6 software to analyze the junctions between the wall and the floor, the wall and the roof, the perimeter of the windows and the projecting corners. Following the calculation method established in the UNE-EN ISO 10211:2012 standard [4], the linear thermal transmittance values of each of the details are obtained, applying equation 1.

$$\Psi = L_{2D} - \sum_{j=1}^{N_j} U_j \cdot l_j \quad (1)$$

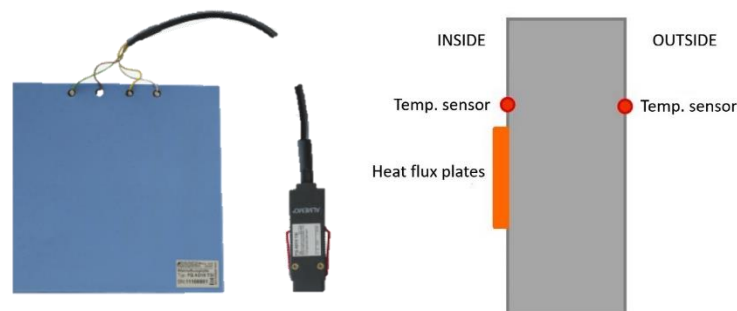
Knowing all the variables that intervene in the previous equation, taking in any case interior dimensions, and performing the calculation for the four described junctions, linear thermal transmittances have been obtained.

Starting from the dimensions of the classroom object of this analysis and the planar and linear thermal transmittances of the enclosures, the heat flux that circulates through the thermal envelope is calculated, according to the following formula included in the calculation method of the UNE-EN ISO 13789:2017 standard [5].

$$H = \sum_i A_i \cdot U_i + \sum_k l_k \cdot \Psi_k \quad (2)$$

#### 4. Experimental campaign

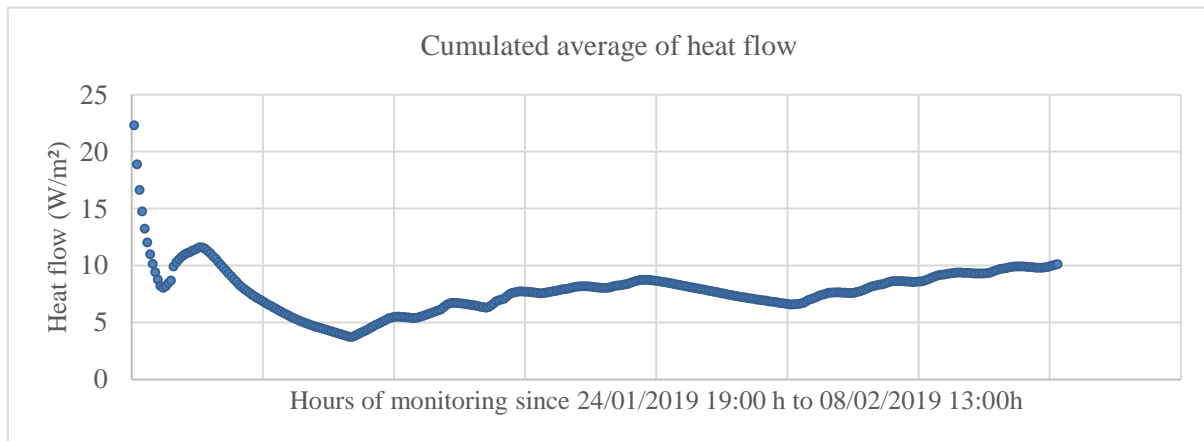
To complete the monitoring installed under the E2Vent project, for the realization of this analysis, a series of sensors has been installed on the north facade of the building, both in the renovated part and in the part that maintains the original state of the walls. Four temperature sensors have been placed, two on the inside of the wall and two on the outside, aligned with the previous ones. In addition, and considering that the purpose of this analysis is to check the heat flow in the enclosure, two heat flow meters are placed inside the classrooms.



**Figure 6.** Heat flow meter and position of the sensors.

The measuring devices have been placed on flat surfaces and away from encounters with other enclosures, that is, in areas where the values obtained are not affected by linear or point thermal bridges, following the indications of ISO 9869-1:2014 [6].

Once the data obtained from the sensors have been stored and studied, the hourly values of temperature ( $^{\circ}\text{C}$ ) and heat flow ( $\text{W}/\text{m}^2$ ) have been extracted and their cumulative average has been calculated. In such a way that the value of the average heat flow of the days in which the monitoring has taken place (from January 24 to February 8, 2019) has been obtained.



**Figure 7.** Cumulated average of heat flow.

## 5. Results

From the analytical method, the thermal transmittances of the enclosures of the envelope and the linear thermal transmittances of the different junctions have been obtained.

**Table 2.** Thermal transmittance results.

$U$ ( $\text{W}/\text{m}^2\text{K}$ )		$\Psi$ ( $\text{W}/\text{mK}$ )	
$U$ wall	0.279	$\Psi$ wall – ground	0.625
$U$ ground	0.997	$\Psi$ wall – roof	0.503
$U$ roof	0.422	$\Psi$ window jamb	0.787
$U$ windows	1.419	$\Psi$ window sill	0.291
		$\Psi$ window lintel	0.311
		$\Psi$ corner	0.737
		$\Psi$ wall – wall	0.291
		$\Psi$ wall – partition wall	0.291

From these data, and considering the previously mentioned UNE-EN ISO standards [5,6], the theoretical heat transfer coefficient through the masonry wall after incorporation of the insulation has been calculated at  $110.1 \text{ W}/\text{K}$ .

On the other hand, from the data obtained after two weeks of monitoring, the resulting heat transfer coefficient in that same enclosure is  $192.6 \text{ W}/\text{K}$ .

As explained in the previous section, monitoring has also been carried out in the wall where no intervention was made in the E2Vent project, that is, the one that maintains its original state. Performing the same analysis as in the previous case, a heat transfer coefficient of  $268.1 \text{ W}/\text{K}$  is obtained.

## 6. Conclusions

On the one hand, and this being one of the main purposes of this study, it is verified that the heat transfer coefficient obtained thanks to the analytical method is in the same range of that resulting from the experimental analysis carried out after the monitoring with heat flow meters. The increase in monitored heat loss over calculations could be due to the safety coefficients used by the different regulations in their thermal conductivity databases, workmanship issues or errors from measuring and logging devices, among other causes.

In addition, and having monitored both the original and renovated state of the building during the same period of time, it has been possible to verify the reduction of the heat flow resulting from the incorporation of 15 cm of insulation to the exterior of the masonry wall. The heat flow is reduced by 26.7%, thus reducing energy losses by transmission through the enclosure. Therefore, thanks to this renovation, energy savings are obtained in the use of the building, a good result both economically and environmentally.

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