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BUILDING MATERIALS FOR THERMAL PERFORMANCE RETROFITTING OF AN OFFICE BUILDING SKIN UNDER CONTINENTAL MEDITERRANEAN CLIMATE

I. A. Djebaili[1,3*], D. Rouag-Saffidine[2,3] and O. Sotehi[2,3]

[1]Faculty of Earth Sciences and Architecture, University of Oum El Bouaghi, Algeria

[2]Faculty of Architecture and Urbanism, University of Constantine 3, Algeria

[3]Energie & Environment Laboratory, Faculty of Architecture and Urbanism, University of Constantine 3, Algeria

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ABSTRACT

In the context of optimizing the buildings energy consumption, the improvement of the parameters of nonperforming building skins may allow a greater energy efficiency and optimize indoor comfort conditions. This is greatly function of the building envelope construction materials characteristics. In effects, the building skin may contain weak points for heat exchange due to poor or missing insulation, provoking significant energy loss. To meet to such a problem, retrofitting strategy can be adopted for reducing energy loss in existing buildings through appropriate materials. For this study, the thermal behavior and envelop performance of an office building was investigated by means of infrared thermography.

Author Correspondence, e-mail: djebaili.imed@univ-oeb.dz

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This provided clear evidence of thermal leaks. Subsequently, a numerical simulation was carried out using TRNSYS software in order compare the cooling and heating needs, first, at actual building, and then after applying a Rockwool external insulation together with energetic performant windows. The results show 28% of energy savings.

Keywords: building materials; energy efficiency; insulation; thermal bridges; simulation.

1. INTRODUCTION

Mastering the existing buildings energy matters presents a major challenge for most concerned actors in the field, whose common concern is to alleviate the current building energy consumption estimated at 36% of the worldwide global final energy use. According to the International Energy Agency statistics [1] 42 Exa joules (EJ) are used to provide heating as the largest single end-use within buildings, and 7 EJ for space cooling.

In Algeria, according to the national energy statement of the year 2017 published by the national agency for the promotion and rationalization of the use of energy [2]. the final energy consumption reached 44.65 million tons of oil equivalent (TOE), of which 43% concerns the building sector. This signals the urgency to intervene in a very energy-intensive sector and take advantage of its great potential for energy saving.

From observation, the actual public services estate park in Algeria, is not constructed with precise energy regulation respect so to allow least energy consuming spaces (specially for heating and cooling. This situation is unfortunately at the origin of unnecessary huge building operative cost which supports investigation inherent to design strategies to achieve indoors offering most favorable thermal conditions at a lower cost possible.

With in mind these reasons, existing buildings retrofitting allows greater energy efficiency with optimum interior comfort conditions. Yet, this depends significantly upon the characteristics of the components constituting the building, especially those of the envelope if one considers its major role of indoor/outdoor environment barrier. For fear that low insulating capacity occurs; the building skin may contain weak points bringing about inefficiency of heat exchange within indoor and outdoor spaces together with significant energy losses. To better control a construction energy ‘behavior’, well performing insulating materials applied to façades could provide a great retrofitting solution letting then subsequent energy loss cutbacks. In practice, it might be advised to proceed to thermal leaks diagnosis and identification through firstly building skin performance analysis.

1.1 Background

Nowadays offices tendency is to depend upon excessive energy-consuming technologies so to ensure environmental comfort requirement, which often results in excessive energy costs for lighting, heating, ventilation and air conditioning [3]. In this sense, a building envelope thermal efficiency constitute plays an important role within a construction energy performance [4]. In practice, such a component is seemingly designed as a separation interface between internal and external environments [5], must meet to a multitude of technical requirements, which can sometimes be paradoxical such as the privilege of natural lighting, solar protection and thermal insulation.

Any envelop energetic performance is incurred by the building material thermal characteristics (Conductivity; Resistance; Transmittance; Resistance of surface; Capacity). According to the effective thermal comfort requirements indoors and external surrounding climatic conditions, a choice of building materials can be completed upon the basis of energy performance optimization. This should allow reaching comfortable indoor conditions all year through with the least recourse to higher cost environmental control systems [6]. In effect, a building energy needs are the result of the balance between contributions and losses through its envelope, in addition to losses by air renewal [7]. Poor or missing insulation provokes significant energy losses leading to significant consequences on building overall energy consumption. This is further emphasized by thermal bridges. According to Theodosiou and Papadopoulos, thermal losses may be up to 35% higher than the initially estimated ones due to the non-consideration of cold bridges in calculation procedures as it often occurs in double brick wall constructions [8]. Besides, in order to decrease office buildings energy consumption, fenestration design should be optimized and carefully treated in all the climate zones [9].

Building envelope retrofit is a process that might be executed once an exhaustive building thermal loads assessment is undertaken. Accurate assessment of the energy savings by building envelope retrofits generally requires detailed hourly simulation programs regarding the complexity of heat transfer in buildings phenomena [10].

Through the previous statements, an accurate evaluation of an envelope thermal and energy performance forms an essential step in the process of improving indoor thermal comfort and optimizing energy expenditure.

Various methods of analysis may be adopted such as infrared (IR) thermography, used for the surface characteristics analysis allowing understanding all present heat transfer phenomena so to identify the thermos-physical properties of building envelopes [11]. In non-destructive way, thermal infrared imaging allows to investigate buildings envelope thermal-energy behavior. Briefing envelope thermal insulation, ventilation, air leakages, moisture and HVAC performance assessment, it also allows the identification of thermal bridges that constitute one of the weakest component increasing heat loss [12]. Therefore, thermal bridges can be evaluated using numerical methods. Simulation of the heat transfer requires the use of numerical calculations for linear thermal bridges and superficial temperatures according to the EN ISO 10211 [13,3].

2. METHODOLOGY

The research methodology of this work consists of the use of:

- In-field thermal imaging seeking envelope weak points;
- Simulation of cold bridges for the transmittance calculation;
- Numerical simulation of the case of study building for the energy consumption calculation before and after improvement proposals.

To this purpose, an office building in the university campus Ain-El-Bey 6 in Constantine 3 University is chosen for the investigation. The university in question is located in Ali Mendjeli (Constantine) located north east of Algeria, (36°16 North and 6°6 East) and characterized by continental Mediterranean climate. According to data provided by Meteonorm 7 software, Winter is cold (January being the coldest month with a temperature averaging 6.6°C and July the hottest with an average temperature of 26.9°C).

Since the purpose of our research is to evaluate the performance of the building through the analysis of the thermal characteristics of its envelope, the variant is the constitution of the skin of the building. Primarily, an in-field thermography is carried out using the ‘Flir One’ thermal camera for the cold bridges and weak points localization. Cold bridges are afterward simulated by the mean of ‘CYPETHERM BRIDGES’ software, where the cold bridges transmittance is calculated, together with a ‘TRNSYS V17’ numerical simulation for the cooling and heating loads in the present state of the case study and after the improvement proposal by Rockwool external insulation layer.

Since the purpose of our research is to evaluate the performance of the building through the analysis of the thermal characteristics of its envelope, the variant is the constitution of the outer wall. The simulation proceeds in two stages: at the envelope actual state and after the Rockwool external insulation panel application.

2.1 Case of study

The case of study is the envelope of the administrative block of the university campus Ain-El-Bey 6 in Constantine 3 University, five storey building envelope built in post-beam structure with 30cm thick double brick wall filling, pierced by 1.4m side square windows. The case of study building and studied floor plan are shown in Figure 1.

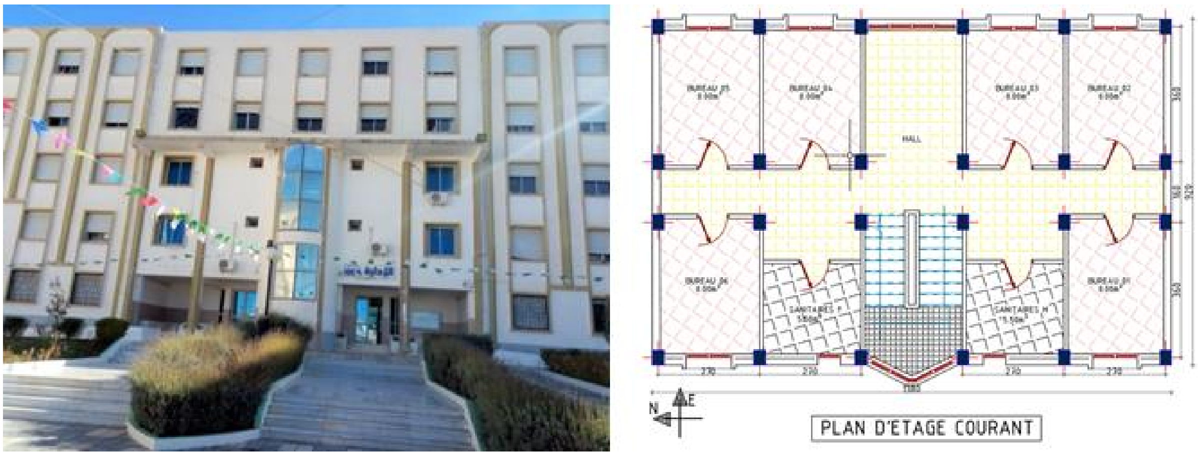


Fig.1. Building main façade and floor plan

2.2 In-field Infreared Thermography

Figure 2 shows the thermal images of the building skin. The color contrast clearly shows the intense presence of thermal bridges, the warm colors represent the heat escaping to the outside. Significant losses through the supporting structure elements (columns and beams) as well as through the simple glazing windows.

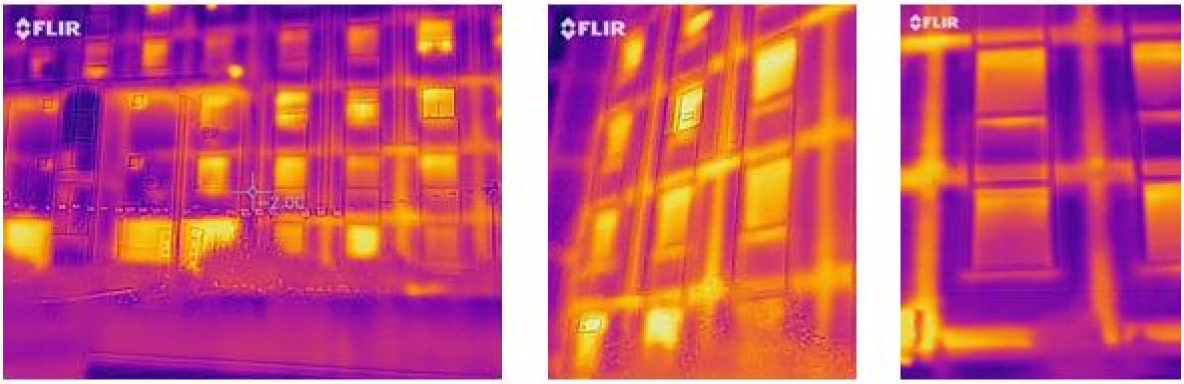
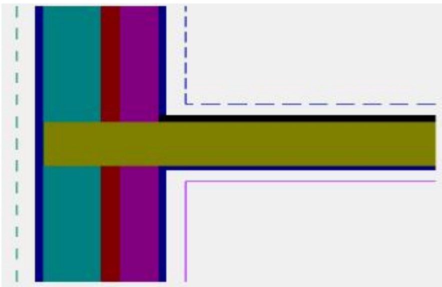


Fig.2. In-field Infrared Thermography

2.2 Numirical simulation

In order to better understand the heat flows phenomena and calculate the thermal transmittance of the cold bridges, we used for this purpose a CYPETHERM BRIDGES software. Table 1 shows the cross section of thermal bridge and its constitution in the two studied configurations, the added insulation is a 5cm layer of rock wool panel with a thermal conductivity of 0.04 W/(m.K).

Table 1. Thermal bridges modeling

At the envelope actual state	**After external insulation panel application**
Generated model:	Generated model:
	
Materials table:	Materials table:

At the envelope actual state — materials table:

	Reference	thermal conductivity W/(m.K)	Thickness (cm)
	Cement mortar	1.4	2.0
	Alveolate brick	0.71	15.0
	Air gap	0.29	5.0

After external insulation panel application — materials table:

	Reference	thermal conductivity W/(m.K)	Thickness (cm)
	Rockwool insulation layer + finishing plaster	0.04	5.3
	Alveolate	0.71	15.0

	Alveolate brick	0.71	10.0
	Reinforced concrete compression slab	1.6	20.0
	Flooring	1.3	3.0

	brick		
	Air gap	0.29	5.0
	Alveolate brick	0.71	10.0
	Cement mortar	1.4	2.0
	Reinforced concrete compression slab	1.6	20.0
	Flooring	1.3	3.0

The simulation of the envelope thermal behavior and energy consumption was carried out by the V17 TRNsys software. The latter makes it possible to simulate the studied office building in dynamic mode. Figure 3 shows a modelling of the local under the TRNsys environment.

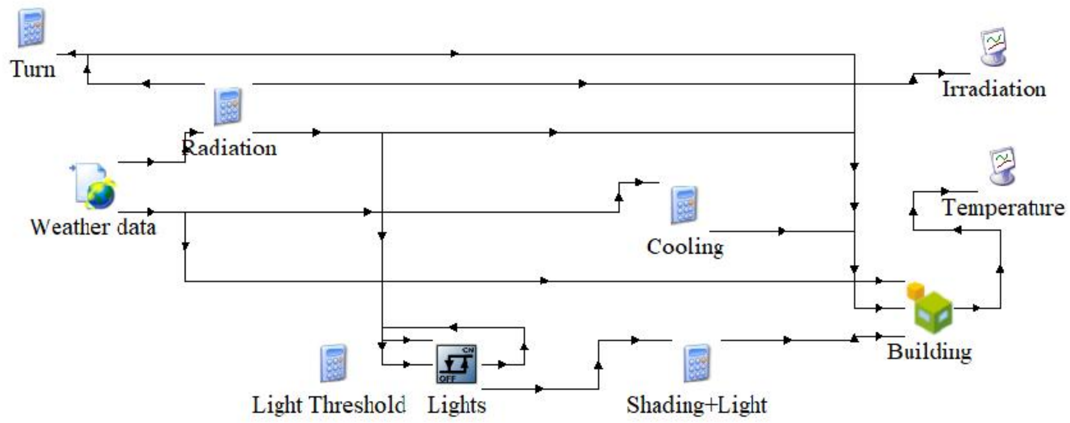


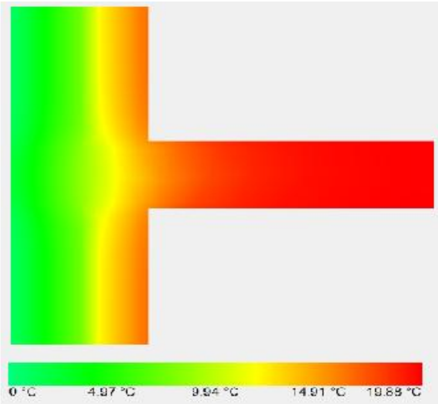
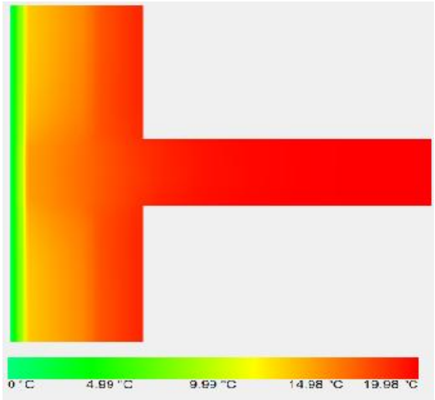
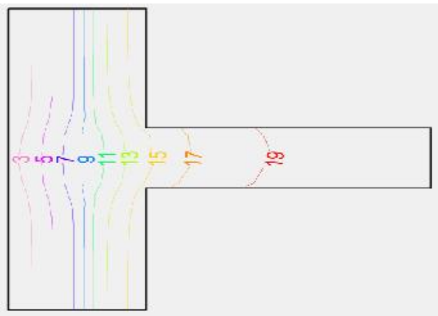
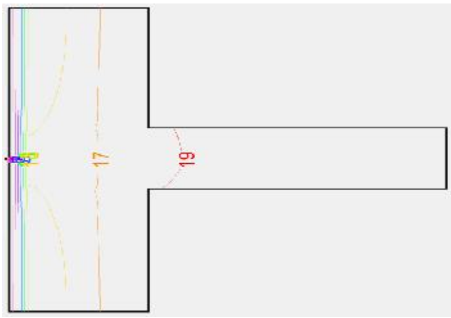
Fig.3. Multizone modeling under V17.TRNsys environment

3. RESULTS AND DISCUSSION

3.1 Thermal bridges simulation results

The temperature distribution and the flow lines shown on Table 2 clarify the difference in propagation, without and with insulation; the insulation board prevents heat escaping to the outside. The results obtained, before and after the application of external rock wool insulation, indicate a decrease of 75% of linear transmittance – 0.385 W/(m.K) before and 0.093 W/(m.K) after. This significates the insulation efficiency in decreasing heat losses through thermal bridges.

Table 2. Thermal bridges modeling results

<table>
<tr><th colspan="2">At the envelope actual state</th><th colspan="2">After external insulation panel application</th></tr>
<tr><td colspan="2">Temperature distribution:</td><td colspan="2">Temperature distribution:</td></tr>
<tr><td colspan="2">
</td><td colspan="2">
</td></tr>
<tr><td colspan="2">Flow lines:</td><td colspan="2">Flow lines:</td></tr>
<tr><td colspan="2">
</td><td colspan="2">
</td></tr>
<tr><td colspan="2">Linear transmittance calculation:</td><td colspan="2">Linear transmittance calculation:</td></tr>
<tr><td>Theoretical heat flow</td><td>13.968 W/m</td><td>Theoretical heat flow</td><td>4.978 W/m</td></tr>
<tr><td>Real heat flow</td><td>21.668 W/m</td><td>Real heat flow</td><td>6.839 W/m</td></tr>
<tr><td>Temperature difference</td><td>20.00 ˚C</td><td>Temperature difference</td><td>20.00 ˚C</td></tr>
<tr><td>Transmittance of the element U</td><td>1.383 W/(m².K)</td><td>Transmittance of the element U</td><td>0.493 W/(m².K)</td></tr>
<tr><td>Calculated linear transmittance</td><td>0.385 W/(m.K)</td><td>Calculated linear transmittance</td><td>0.093 W/(m.K)</td></tr>
</table>

3.2 TRNsys simulation results

In this part of work, we present the results of using thermal insulation on indoor thermal comfort and energy consumption. The analysis of the thermal images indicates heat losses through thermal bridges and windows. That is why the improvement proposal consists on insulating the external building skin and replacing the existing single glazing windows by low-emissive double-glazing windows with Argon gas.

The Figure 4 shows the heating, air-conditioning and total loads for the offices under study.

Heating requirements decrease from 6956 kWh (initial case) to 4003 kWh (improved case), a reduction of 42% and air conditioning from 8658 kWh (initial case) to 7314.00 kWh (improved case) (16 % of reduction). Thus, a reduction of 28% is obtained for use of external rock wool insulation layer.

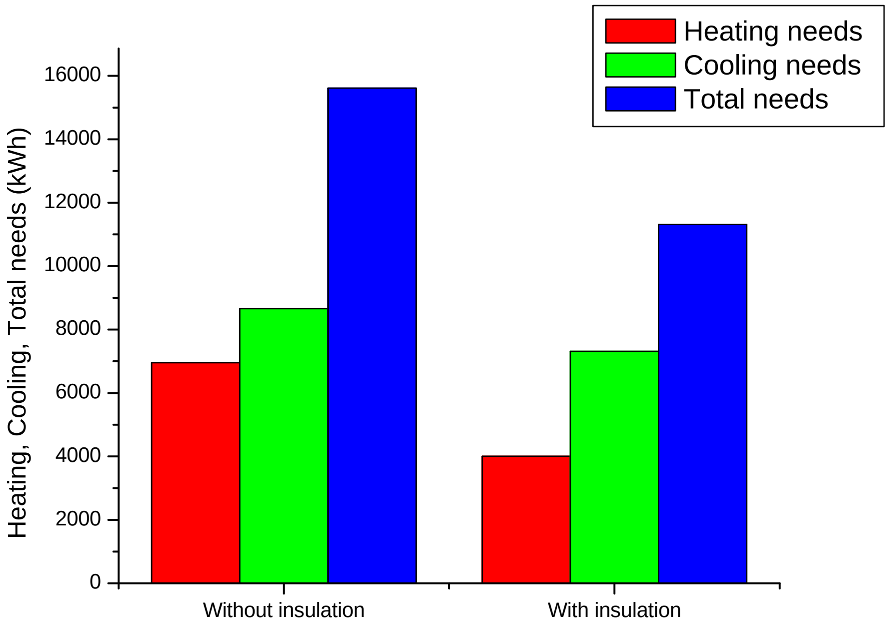


Fig.4. The heating, cooling and total needs for both cases studied

Afterward, we evaluated the cold wall effect by assessing the impact of the wall composition on inner surface temperature of the offices. The west wall shown on thermal images is selected to perform the calculations.

Figure 5 illustrates the variation of the surface temperature of the selected elements. The interior surface temperature of the wall with insulation is higher than that of the wall without insulation and varies between 18 and 19°C with a difference up to 1.2°C. However, for glazing the difference is huge and reached 8°C. The surface temperature of the double glazing with Argan varies between 16°C and 24°C and the single glazing between 8.5°C and 18°C which induces a significant loss of heat and a feeling of thermal discomfort. It should be noted that the Passivhaus standard requires a surface temperature of glazing greater than 17°C [14].

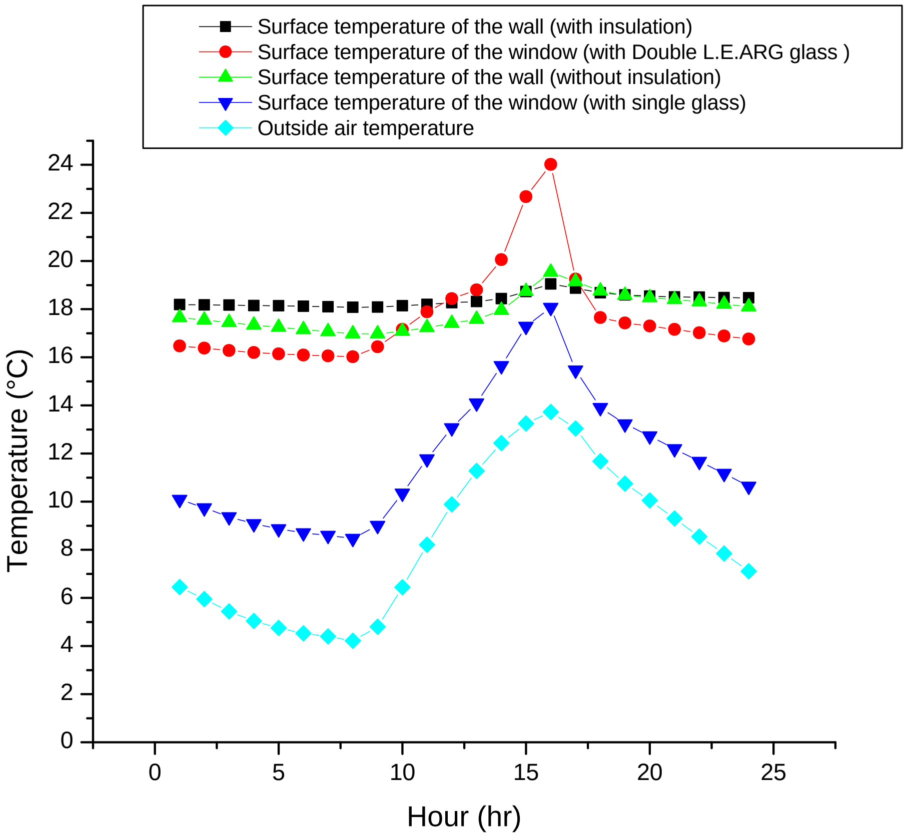


Fig.5. Wall and glazing surface temperatures

4. CONCLUSION

The building envelope constitutes a key element in reducing building energy consumption. This work (part of a PRFU research project [15]) confirmed that external thermal insulation allows an effective reduction upon the impact of thermal bridges, as well as upon the optimization of comfort conditions indoors.

The thermography analysis of the herein study envelope gives substantial evidence of the intensity of thermal loss through cold bridges and windows. An external thermal insulation with a performing glazing for the current retrofitting proposal. Subsequently, a verification was carried out by using numerical simulation. On this basis, we conclude that:

- A registration of reduction of 42% and 16% in respectively heating and cooling requirements.
- External insulation and efficient glazing leads to 28% reduction of the total energy consumed per storey
- The insulation of the walls increases the internal surface temperature (cold wall effect

elimination), consequently the improvement of the thermal comfort.

- The use of a high-performance glazing not only limits thermal losses but also increases its surface temperature. The surface temperature obtained after improvement is suitable for the international standard and therefore increases the energy efficiency of a standard Passivehaus.

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