

Historical Buildings in Protected Areas in Italy: A Re-Design Study of a Rural Building

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Abstract

Historic and traditional buildings, including rural ones, are a territorial resource in Europe and constitute an integral part of the European cultural heritage. However they are often characterized by poor energy performance and a large potential for energy retrofit actions.

On the other hand, the hardest part in retrofitting such buildings is the limited invasiveness that such actions need to have on the historical and heritage value of the building itself.

The paper describes an experience of re-design of an existing rural building located in Sicily, inside the ancient Greek Valley of the Temples.

An energy audit was performed on the building, its energy uses thoroughly investigated. A building model was developed in the TRNSYS environment and its performances validated. The validated model was used for re-design studies aimed towards the improvement of the energy performances of the building in compliance with the legislation. The best performing solutions to be applied to a case-study like the Sanfilippo House are those regarding the management of the building, as in the case of the natural ventilation and the HVAC setpoints that would allow a large impact (up to a 10 % reduction in energy uses) on the energy performances of the building with no invasiveness, and those with very limited invasiveness and high impact on the energy efficiency of the building, as in the lighting scenario (up to 30 % energy use reduction). The most invasive actions can only be justified in case of high energy savings as with the insulation of the roof, otherwise they should be disregarded.

1. Introduction

Historic and traditional buildings, including rural ones, represent one important territorial resource in many European cities and are an integral part of the European cultural heritage (Tassinari et al., 2007). However, they are among the largest contributors to the poor energy performance of the building sector (Tadeu et al., 2015) in Europe since they often have poor envelopes and un-optimized HVAC systems that contribute substantially to CO₂ emissions, rising energy bills and increasing indoor environment quality issues (Bastian et al., 2014). This represents a large potential for energy efficiency that needs to be tapped if the ambitious targets of decarbonisation discussed at the latest COP meetings are to be met in the future.

For example, a study based on building energy modeling found that the refurbishment of half of Europe's buildings built before 1945 with an average of factor 4 reduction in the heat transmittance (U) of the opaque structures could result in a reduction of 5.6 % of the total energy demand of buildings (which represents 2.25 % of the total energy consumption) (Climate-KIC, 2013).

In Italy, 60.44 % of the buildings were built before 1976 (13.15 % before 1919, and 22.90 % between 1919 and 1945) (Fabbri et al., 2011). In detail, over 3,900,000 buildings were built before 1920 and several of these constructions are characterized by historical and artistic values, therefore protected as cultural heritage (Ascione et al., 2011). Furthermore, there are 1,376,304 rural buildings used in continuous or seasonal activities, 68 % of which are used to store farm machinery and equipment; 1,084,038 are

animal shelters, 45 % of which were built or restored before 1970; the stock of housing within farms amounts to a total of near one million and a half units 1,460,980, 358,422 of which are unoccupied (Candura et al., 2008).

It is often difficult to operate energy retrofits in the context of historical buildings, since the main focus is the achievement of higher energy performances without compromising the architectural and historical value of the building (Dalla Mora et al., 2015; Pisello et al., 2016; Tadeu et al., 2015).

Moreover, the regulation in Italy makes a clear difference between historical buildings and non-historical ones. Regarding the former, they are excluded from the fulfilment of minimum energy requirements, even after retrofits. Furthermore, the retrofit itself is to be subjected to a feasibility verification in order to identify whether the action configures as an “unacceptable alteration of the historical character” of the building (Presidenza Repubblica Italiana, 2015).

Since the potential for energy efficiency enhancement in existing buildings is so large (Beccali et al., 2013), the EU has paid widespread attention to this topic. In 2014 the energy efficiency Directive highlighted the need for member states to submit National Energy Efficiency Action Plans and a long-term strategy in the field of building renovation to reach a higher energy efficiency. Also, member states are required to renovate 3 % of the total area of conditioned buildings.

The Energy performance of buildings Directive, by introducing the Net Zero Energy Building concept (Cellura et al., 2015), has tried to promote energy efficiency with the built environment, as well as the on-site generation through the exploitation of renewable energy sources (Beccali et al., 2007).

In this context, the paper describes the experience of a re-design of an existing rural building located in Sicily, inside the well-known ancient Greek Valley of the Temples, that mostly hosts the administrative offices of the park.

An energy audit was performed on the building, its energy uses thoroughly investigated. A building model was developed in the TRNSYS environment (University of Wisconsin, 2012) environment and its performances was validated. The validated model was used for redesign studies to improve the energy

performances of the building in compliance with the limitations set by the legislation.

The study aims to the simulation of energy efficiency actions to be implemented inside the building in compliance with the limitations coming from its status of heritage building.

The work is one of the plans of the CRIM-SAFRI Italy Malta cross-border cooperation projects.

2. The Case Study

The building is called Sanfilippo House and it is located in the city of Agrigento, in southern coastal Sicily.

The building is very close to one of the most relevant examples of Magna Grecia in Italy and has been a UNESCO Heritage Site since 1997, the Valley of the Temples (Figs 1 and 2).



Fig. 1 – South view of the building



Fig. 2 – Aerial view of the building (Google Maps)

The main body of the building is L-shaped (Figs 3–4), with the main entrance located in the North, it leads directly into the conference hall, marked by the red arrow. All around it, in the two sections of

the L, the building houses offices. Restrooms are located outside the core of the building and are located in the smaller construction at the far North of the plan.

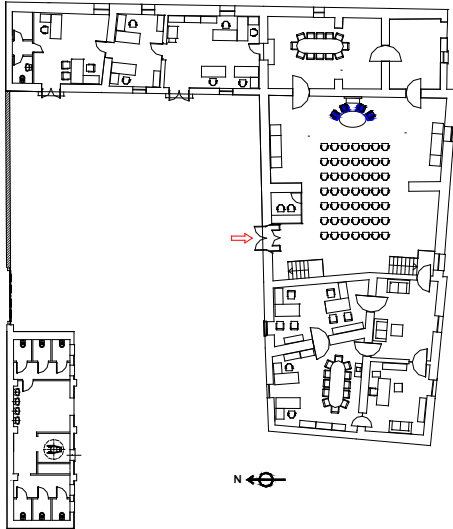


Fig. 3 – Plan of the main body of the building (first level)

The basement of the building includes more offices and technical spaces (Fig. 4).

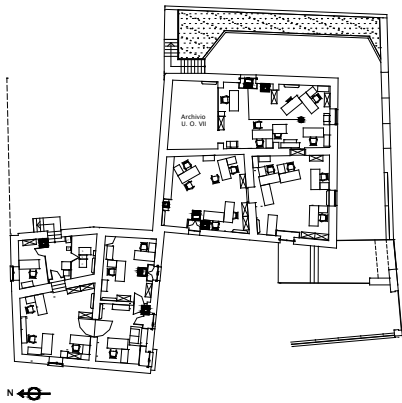


Fig. 4 – Plan of the main body of the building (basement)

The building is characterized by a total floor surface of about 730 m², a height of about 5 m and a shape factor $S / V = 0.51$. The envelope is characterized by tuff outer walls, with $U=0.74 \text{ W/(m}^2\text{K)}$ with a total thickness of about 0.8 m; externally there is a coating with stone and mortar; internally the walls are plastered and painted with lime and gypsum. The pitched roof ($U=2.55 \text{ W/(m}^2 \text{ K)}$) is made of brick tiles on wooden decking; the wooden beams are

exposed; all rooms are made of terracotta bricks. Floors are 160 cm thick and have a U value of $0.43 \text{ W/(m}^2 \text{ K)}$.

Windows use single glazing (overall average $U=6.5 \text{ W/(m}^2 \text{ K)}$) while door-windows are double glazed (overall $U=1.86 \text{ W/(m}^2 \text{ K)}$); window to wall ratios are never higher than 5 % in all facades and orientations.

The use of the building is non-residential, not more than 50 occupants can be inside the building simultaneously. Work times are from 7:30 am until 2:00 pm, every day from Mondays to Fridays, while on Wednesdays from 7:30 am to 6:00 pm. Fluorescent tubes of different sizes give lighting. Internal increases are mainly based on office equipment, mostly personal computers (27 in the whole building) and printers (25). Working schedules for machines follow exactly the occupancy pattern in the building, printers' peak power due to non-contemporary use is equal to 20 % at the most. Also lightings follow a variable use pattern that takes into account both the occupancy levels and the availability of natural light during the year. Heating and cooling equipment are considered on as long as the building is occupied.

The building is conditioned through an air-water heat pump with R410A and fan coil units. The fan distribution is a function of the geometrical and thermal characteristics and based on the number of occupants. The HVAC system works from December 1st, to March 31st in heating mode and from June 10th to September 10th in cooling mode.

Thermal imaging studies were performed as well during the energy audit to determine the quality of the envelope and the presence of thermal bridges (Figs 5–7). Such an approach fits perfectly the limited invasiveness required for monitoring and diagnosing techniques to be used in a protected site.

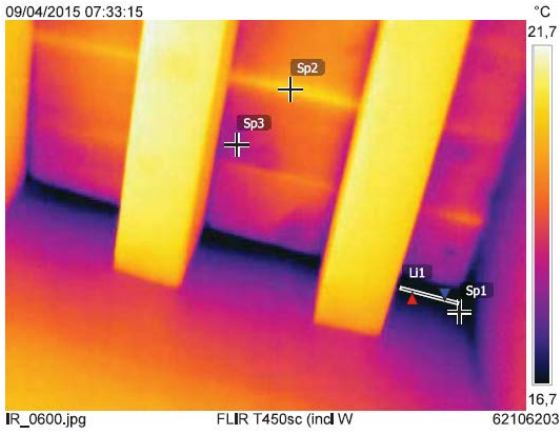


Fig.5 – IR image of the roof

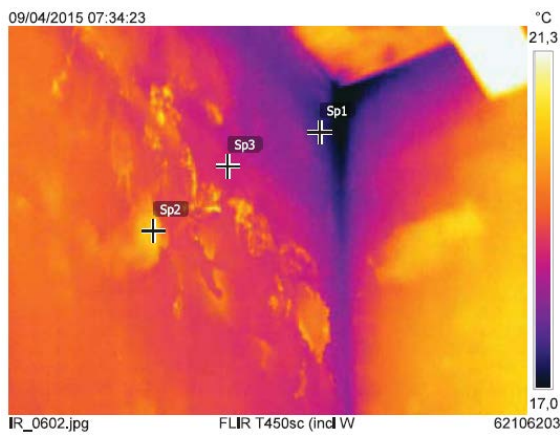


Fig.6 - IR of East oriented internal walls



Fig. 7 – IR of the main North facade

The limits of the envelope are clearly highlighted by Figs 5–6. Thermal bridges are clearly visible in both the internal roof and the external facades. In Fig.5, thermal bridges are highlighted whereas the temperature on the roof is below the average up to 4-5 °C. In Fig. 6 a defective internal plaster layer is

available and the thermal bridge in this case, causes a temperature difference with the rest of the opaque wall of 4.3 °C.

In Fig. 7 a defective insulation is evident, as the external temperature in the opaque structure is variable from 10 to 13 °C on the whole façade. This highlights one of the most problematic aspects in establishing the performances of heritage and historical buildings: the low performances of the envelope make it difficult to quantify the most correct assumptions to be implemented in building modeling. The results of the IR images have identified defective insulation in the envelope and are used to introduce corrections to the theoretical U value of the walls in the model to take into account the thermal bridges.

Another critical aspect in most historical and heritage buildings is the lack of detailed energy meters to quantify the energy flows within the building and the difficulty in installing even temporary ones.

As such, all the energy use profiles were determined based on working times, interviews of the occupants, and calculation of the maximum power installed. The only available data was deduced from the energy bills that led to the information reported in Fig. 8.

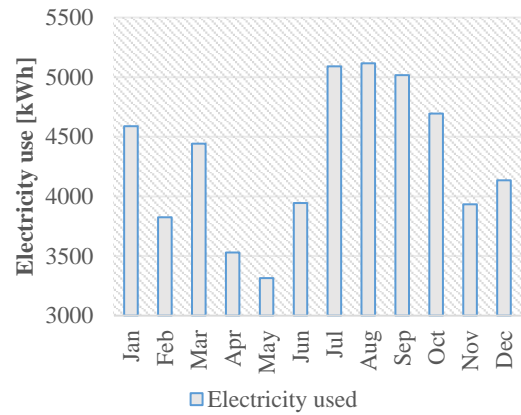


Fig. 8 – Energy bill monthly electricity use

As per the energy bill preliminary calculations, overall electricity energy uses amount to roughly 69 kWh/m² (51 MWh/year).

3. Modeling

The modelling of the building was performed in the TRNSYS environment. Due to a vast homogeneity of the building thermal zones in terms of use profiles, occupation, and adopted thermal system, also in compliance with the Italian technical regulations, we opted to define one thermal zone per plan.

The heat pump is modelled with a fixed Coefficient of Performance (2.92) and Energy Efficiency Ratio (2.4) with 27 °C and 18 °C as cooling and heating setpoints, respectively.

Internal loads for lighting are assumed to be 5 W/m² for the whole building; when active, internal loads for personal computers are assumed equal to 72 W, while for printers the value input to simulation is 50W.

Natural ventilation and infiltration is modelled through TRNFLOW (Transsolar, 2009), establishing a pressure network in the model. The nodes represent the rooms and the building surroundings (Weber et al., 2003). In the baseline model windows are to be closed throughout the year.

The TRNSYS model outputs were compared with the energy bill monthly information to validate them critically. Results are shown in Figs 9 and 10.

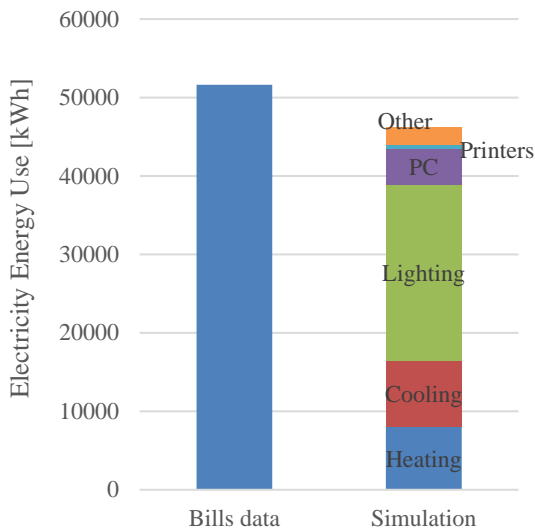


Fig. 9 – Validation of the simulation, annual data

Heating represents 17.34 % of the total electricity consumptions, cooling is very close to this value (18.38 %), while the highest contribution to the total is the electrical equipment and lighting (64.28 %).

Lighting in particular amounts to about 48 % of the electricity use in the building.

On a yearly base, the simulated results report a deviation from the bills data close to 10 %. While this is usually the threshold accepted worldwide in several standards (ASHRAE, 2014) for validation of models, a more in-depth analysis would allow relating these results to some contingent issues.

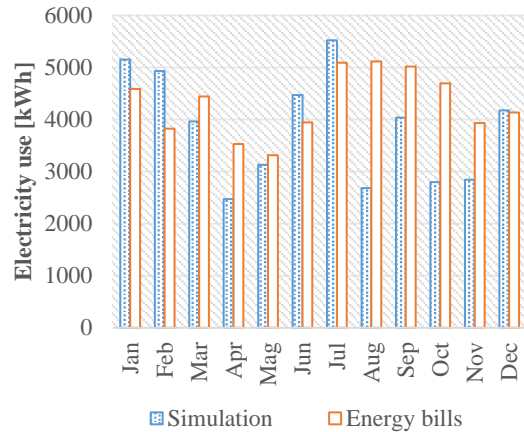


Fig. 10 – Validation of the simulation, monthly data

The analysis in Figure 10 shows some differences between the energy bills data and the simulations in some months and results nearly identical in others. These differences are connected to some behaviour of the occupants, different work hours in some specific parts of the year than what were implemented in the model and to the use of a standard weather file during the simulation. Moreover, only one year of energy bills was retained in the administrative offices of the building and as such it was the only quantitative reference available. The wide and non-quantifiable use of a portable air conditioner was registered as well for the summer period, which is one of the causes of the more pronounced differences in the hotter months.

The model is however able to reproduce the general trend with moderate differences with the energy bills, and as such, is considered appropriate for the development of the building redesign studies.

4. Redesign

From the analysis of the building and of the results, it is possible to define some retrofit actions to improve the energy performances of the building. The context in which to operate is bound by non-technical constraints. As such the approach was to target first the easiest and simplest reductions in energy use with no structural interventions, while only afterwards to include progressively more invasive retrofitting actions. In this section of the paper, the energy efficiency and retrofitting solutions proposed are reported and briefly discussed. All the retrofitting solutions proposed were analyzed singularly and the energy saving potential was evaluated comparing all the retrofitting solutions with the same baseline case.

4.1 Natural Ventilation

Benefits from promoting the use of natural ventilation in mixed mode buildings range from an increase in the air quality of the offices to a substantial reduction in energy use.

The use of natural ventilation in the building is modeled by implementing a mixed-mode building control in the simulation, that includes the manual opening of the windows when overheating occurs ($T_{\text{indoor}} > 26$) and while external temperature is below $26\text{ }^{\circ}\text{C}$ as well. If internal temperature rises higher than $27\text{ }^{\circ}\text{C}$, the standard cooling equipment will be operating.

Although cooling was not the highest contributor of the energy use in the building, this solution could allow the savings of nearly 20 % of the whole cooling energy required during the year (1650 kWh), equal to 5.50 % of the total energy savings.

4.2 Adaptive comfort considerations in the use of cooling equipment

As a complimentary measure to the previously discussed one, this scenario investigates the benefits of a variable cooling setpoint towards the reduction of energy uses.

Under the premises of UNI EN 15251 (European committee for Standardization, 2007) and its future revision prEN 16798-1 (European committee for Standardization, 2015), it is possible to associate the

concept of adaptability of subjects living in a considerably hotter environment to the capability of perceiving a higher indoor temperature as comfortable. Although adaptive comfort in mixed-mode buildings still needs further research, this scenario includes a higher setpoint temperature for the activation of cooling systems while allowing the opening of windows while temperature is below it. The setpoint is calculated as based on the equation of the comfort temperature reported in the UNI EN 15251; if the indoor temperature is higher than $29\text{ }^{\circ}\text{C}$, however, windows will be closed and the cooling system will be activated.

This scenario forecasts a 55 % reduction in the cooling energy use (5650 kWh_e) and an overall reduction of nearly 10 % in overall energy uses.

4.3 Substitution of lighting elements with LED

The largest source of potential energy efficiency actions in the building is the lighting system (nearly 50 % of overall consumptions). The existing fluorescent tubes can be substituted throughout the building with LED elements that guarantee a higher visual comfort and high electricity savings.

The modelling includes a variation in the power installed while it grants the same illuminance levels to the indoor environment.

This solution could guarantee a reduction of up to 60 % of the lighting consumptions and of nearly 30 % of total electricity use in a year.

4.4 Substitution of windows and frames

Another potential source of inefficiencies in the building energy management are the windows, since most of them are single-glazed. Double glazing windows could allow in the whole building a reduction of heating requirements due to both the reduction of infiltration airflow and transmittance values.

This scenario includes the substitution of single glazing windows with double ones, having $U=1.06\text{ W}/(\text{m}^2\text{ K})$, solar transmittance $g=0.548$ and visible transmittance $T_v=0.769$.

This scenario could reduce energy the use for heating by roughly 6 % but as a drawback could increase

cooling energy requirements by 2 %. Overall electricity use reduction on a yearly base will not be higher than 1 %.

4.5 Internal insulation

The transmittance values for all opaque structures are above the normative limitations in Italy for new buildings (roof= $U=2.55\text{W}/(\text{m}^2\text{ K})$, vertical opaque elements $U=0.74\text{ W}/(\text{m}^2\text{ K})$).

The retrofit intervention studied is to add internal insulating coatings to the vertical opaque structures and the roof. Although it would be more beneficial to the energy performances of the building to actually expose thermal mass towards the inside, altering the facades in such a deep way, is not considered a viable option.

By adding internal insulation, the U values for both the opaque vertical structures and for the roof will be reduced respectively $0.343\text{ W}/(\text{m}^2\text{ K})$ and $0.29\text{ W}/(\text{m}^2\text{ K})$. In the first case, the insulation of opaque structures can reduce the energy use during the year by 1.70 %, cooling can be reduced up to 2.3 % and heating by 7.4 %.

Higher values are reported for the insulation of the roof that can reach 8 % of the overall yearly electricity use reduction and of both heating (62 %) and cooling (51 %) energy requirements.

4.6 Recap

Several retrofit solutions have been examined in the paper, ranging from purely energy management choices to actual retrofit interventions to the existing environment.

Table 1 reports briefly all the energy savings identified, while focusing both on the single energy use (e.g. heating) and on the overall energy consumptions.

The results identify energy savings in the case of positive values while it marks an increase of energy consumptions if the values reported are negative.

Table 1 – Recap of the simulation scenarios

	Heating	Cooling	Lighting	Overall
Natural vent.	-	19.20 %	-	5.50 %
Adaptive comfort	-	54.81 %	-	9.92 %
LED	1.39 %	-6.25 %	59.10 %	30.02 %
Windows	5.94 %	-2.01 %	-	0.66 %
Vertical walls	7.41 %	2.28 %	-	1.70 %
Roof	62.02 %	51.10 %	-	7.86 %
Redesign	78.60 %	90.36 %	59.10 %	44.46 %

A contemporary application of all these solutions, indicated in Table 1 as “Redesign”, could allow an overall reduction in energy consumption of roughly 44.5 %, with very large reductions in heating, cooling and lighting energy use.

5. Discussion

The results analysed have identified several redesign solutions and actions with different potential to increase the energy efficiency of the building. However they do not have the same impact either in terms of invasiveness and feasibility in a heritage building.

Several other potential solutions were investigated at first but later removed, due to their too large invasiveness on the features of the environment and of the building itself.

It was the case of wind turbines that would disrupt the visual impact of the historical park, as well as photovoltaic systems that could have completely reworked the facades and the appearance of the rural building under study.

The easiest retrofitting scenarios are therefore the least invasive approaches that can guarantee the highest energy savings. From this perspective, the first two scenarios (natural ventilation use and application of variable setpoints) come as perfectly tailored for such a building, whereas the only needed actions are better strategies for the management of the openings and of the HVAC system. These solutions highlight relevant energy savings that could be achieved through the development of a wider energy awareness by the occupants of buildings with no costs and zero impact on the historical value of the building.

The largest energy reduction is achievable through the substitution of the lighting elements with higher performance LED. Aside from the limited impact on heating and cooling, this scenario can guarantee a relevant increase in performance with a modest impact on the building, with little to no invasiveness. This scenario, due to the specific nature of the energy consumptions of the building, proves the best and most impacting one, representing a very effective compromise between invasiveness and effectiveness.

The substitution of windows and frames, usually regarded as effective in existing buildings in similar conditions needs to be contextualized to the Sanfilippo House and in general to similar buildings, with very massive envelopes and very limited transparent surfaces. Having less than 5 % of glazed surfaces on all facades, while having even no windows in some, will indeed limit the effectiveness of a retrofit of the windows.

The solution has a very limited impact on the performances of the building. Achieving only a 6 % reduction of the overall heating consumptions, while performing a moderate invasiveness retrofit action in a heritage building, which is probably not the best choice in this context. Moreover, allowing moderately higher infiltration values could help in having healthier conditions indoor, in a building that does not have high airflow interaction with the outdoor environment.

Applying internal insulation to the vertical elements and to the roof leads to different results, mostly in accordance to the difference in the original transmittance values in the two cases. Having a transmittance equal to $U=2.55W/(m^2 K)$, the retrofit of the roof leads to the best results, up to nearly 8 % in the overall electricity use reduction, while for the vertical walls this value could reach only 1.7 %.

Although these solutions could be performed even on a heritage building, while the retrofitting of the roof is necessary, since it could cut by more than 50 % both heating and cooling, the vertical walls have only limited positive impacts on the results, and as such could be removed from the final implementation to preserve as much as possible the integrity of the historical value of the building.

6. Conclusions

The study has presented a case study of a typical rural heritage building of Southern Italy, built close to the archaeological site of the “Valley of the temples” close to Agrigento, Sicily.

The aim of the study was to develop a retrofit study to be viable in a heritage context, with the achievement of good results while being respectful of the historical value of the building itself and of the overall site in which the building is built.

The main focus was given to the selection of a range of retrofit solutions with the lowest impact and invasiveness to the value of the building.

The best performing solutions to be applied to a case study like the Sanfilippo House are those regarding the management of the building, as in the case of the natural ventilation and the HVAC setpoints, and those with very limited invasiveness and high impact on the energy efficiency of the building, as in the lighting scenario.

The most invasive actions can only be justified in the case of high-energy savings as in the case of the insulation of the roof; they should otherwise be disregarded.

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