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The attic and its effect on the energy performance of historic buildings

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Abstract

This paper aims to investigate the problem of attics conservation or dismantling from historic buildings. The attic, unconsciously inherited and planned with the traditional building techniques, constitutes a precious architectural heritage in the field of historic housing in the whole European patrimony. In many cases, the peculiarities of the type of techniques and the use of traditional local materials are the reasons why attics constitute an evidence of an active culture of know-how that has to be preserved. Furthermore, the attic-mediated heat transfer between indoor and outdoor environments, contributes to the saving of building heat loss. Nevertheless, the practice of eliminating attics is particularly diffused, and building owner or architects, preferring to dismantle their structure, compensate this loss by using insulating boards to constitute the final roofing section.

Keywords: Attic; Heritage Building; Heat transfer coefficient; ISO 13789.

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1. Introduction

Studies on local materials and construction techniques constitute a complex heritage of knowledge and expertise. This kind of patrimony converts the empirical know-how, which characterize past populations and places, in technical culture. Since time immemorial, the selection of the construction material is connected with its availability, its manageability, its resistance to natural and human induced decay, and, most importantly, the climatic context.

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Frequently, constructive technologies and modern materials selected for interventions aimed at monitoring energy consumption of an ancient building, are in contempt of the traditional building techniques. Furthermore, the global improvements in terms of performance, compared with the starting conditions, are not always achieved.

Ceilings (or false-ceilings) elimination and the loss of attic as a typological peculiarity of some historic buildings is a common practice in Italy, where roof transmittance is, instead, improved by a covering thickening, made by the addition of insulating layers. This procedure not only involves an increase in the net volume air-conditioned space, but also determines the loss of precious information about the original constructive characteristics of the building, and the different materials and techniques employed to create the authentic language of the local building tradition.

The ventilated roof is nothing but the translation of the old attic, constructed with the modern green buildings techniques. The attic ventilated and cooled the building during the summer, when the windows were left open, while insulated during the winter, when the windows were left closed. The air chamber, enclosed in a ventilated roof, acts as a climate filter towards the outdoor environment, allowing the intrados of the ceiling to remain fresh in order to make comfortable the use of attic.

Currently, the insulation of the building envelope represents the main strategy to control energy consumptions, during both winter and summer, without taking into consideration the characteristics of the climate. According to D'Orazio et al. [1] this approach is responsible for the spread of construction technologies and materials that do not adhere to the traditional construction methods. Additionally, excessive insulation of buildings raises the risk of reducing the effectiveness of passive cooling strategies (thermal mass, roof ventilation) and could have undesirable effects on the indoor comfort.

The strategy of attic ventilation is one of the most widespread techniques to reduce the accumulation of heat in the interior spaces of a building. According to the studies of Karam Al-Obaidi [2] the benefits of ventilated attic consist in the possibility of controlling the high levels of energy consumption. Furthermore, the influence of ventilated attic on the building thermal performance has been studied by Dimoudi et al. [3] who demonstrated the effectiveness of the ventilation (and radiant barriers) in the roof in reducing solar heat gain during the summer.

The need to properly calibrate the size and the placements of the insulating layers on the roof has been stressed by the study of Ozel and Pihtili [4] on the effects of the addition of one or more levels of insulation on 12 different configurations of the roof. They claim that the best solution is to place three pieces of insulation of the same thickness, one on each side and one at the center of the roof. The same topic has been studied by Ben-Nakhi et al. [5], leading to the conclusion that it is possible to save energy only when the insulation is properly positioned.

Nomenclature

V	Volume
S	External Surface
H	Heat Transfer Coefficient
$_D$	Direct heat transfer
$_U$	Unconditioned spaces
$_R$	Roof
$_W$	Wall

2. Goals

The aim of our research is to study the thermal influence of the attic on ancient buildings. In particular, we seek to evaluate circumstances in which attic conservation or elimination is preferable. We compare two case studies, representing two models of the same house, one with and one without attic, in terms of global heat loss values. We calculate the respective values of H, heat transfer coefficient, intended as the sum of H_T, transmission heat transfer coefficient, and H_V, ventilation heat transfer coefficient. In particular, we evaluate in what way and how much H value varies as a function of the physical quantities that influence the heat transfer coefficient amount, together with the conditions, linked to particular transmittance values, volumes or external surfaces building elements, that determine that the heat loss of the first case study to be greater or lesser than the second one.

3. Methodology

In the present study, the heat transfer coefficient (H_T) is calculated according to the Standard EN ISO 13789. The methodology consists of a comparison between two different coefficient H_T, one calculated in the building provided with the attic, and the other calculated in the same building, but in the absence of the attic.

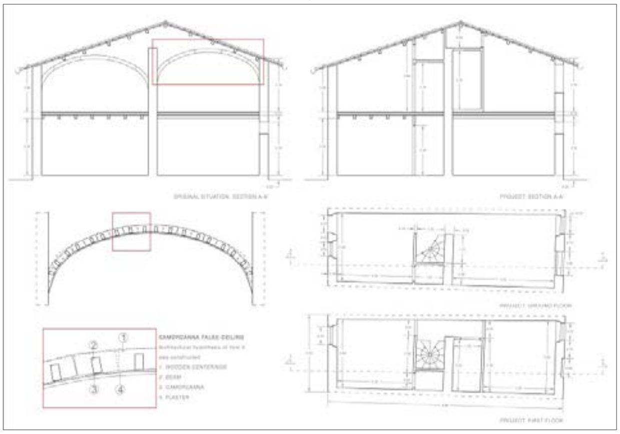

Fig. 1. The terraced house located in Borgo Marecchia (RN). Compare the *ante operam* and *post operam* situation and the transformations underwent by the building. Bottom left, a reconstructive hypothesis of the original camorcanna vault.

3.1. Case study

The phenomenon of restoration, rehabilitation or renovation of residential historic buildings, arisen after the implementation of the seventies recovery plans, is common in Emilia-Romagna. With these interventions, the traditional ceilings have been indiscriminately dismantled, leaving the wooden roof beams visible. The choice of using thermal insulation panels to compensate for the ceiling elimination, in many cases has altered the thickness of the covering package, together with the original position of elements and the look of eaves and cornices, erasing their original formal conception.

The case study is taken from a nineteenth-century terraced house located in Borgo Marecchia, an ancient fishing village in Rimini (Fig. 1).

We model the pre and post-intervention buildings by creating two simple volumes, one with and one without the attic. Of note, the simplification of the buildings in two models is aimed at easily calculating the overall heat loss in the two case studies.

- Case study A: a building with two floors, a pitched roof, *without the attic*;
- Case study B: a building with two floors, a pitched roof, *with the attic*.

3.2. Mathematical formulas and simplifications adopted

Below, we report the Standard EN ISO 13789 simplified formulas necessarily adopted for this paper. The transmission heat transfer coefficient is calculated according to the Equation (1):

$$H_T = H_D + H_g + H_U + H_A \tag{1}$$

where $\mathrm{H_D}$ (W/K) is the direct heat transfer coefficient between the heated or cooled space and the exterior through the building envelope, defined by simplified Equation $\mathrm{H_D = \Sigma_i \cdot A_i \cdot U_i}$, where $\mathrm{A_i}$ ($\mathrm{m^2}$) is the area of element i of the building envelope; $\mathrm{U_i}$ $(\mathrm{W/m^2 \cdot K})$ is the thermal transmittance of element i of the building envelope.

$\mathrm{H_U}$ (W/K) is the transmission heat transfer coefficient through unconditioned spaces (our attic) defined in Equation $\mathrm{H_U = H_{iu} \cdot b}$, where $\mathrm{b = H_{ue}/H_{iu} + H_{ue}}$, where $\mathrm{H_{iu}}$ (W/K) is the direct heat transfer coefficient between

the conditioned space and the unconditioned space; $\mathrm{H_{ue}}$ (W/K) is the heat transfer coefficient between the unconditioned space and the external environment; $\mathrm{H_{iu}}$ e $\mathrm{H_{ue}}$ include the transmission and ventilation heat transfers. They are calculated according to Equations $\mathrm{H_{iu}} = \mathrm{H}_{T,iu} + \mathrm{H}_{V,iu}$ and $\mathrm{H_{ue}} = \mathrm{H}_{T,ue} + \mathrm{H}_{V,ue}$
The transmission heat transfer coefficient is calculated according to Equation:

$$H_V = \rho_a \cdot c_p \cdot \dot{V} \tag{2}$$

where V is the airflow rate through the heated or cooled space; $\rho_a \cdot \mathrm{c}_p$ is the density and the heat capacity of air per volume.

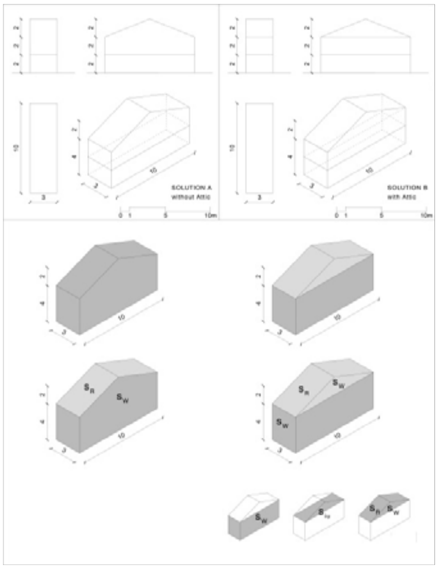

Fig. 2. Illustrations of calculations made for conditioned and unconditioned volumes and external surfaces, of the two case studies

4. Results

Table 1 reports results of simulations and Fig. 2 reports geometrical data of conditioned and unconditioned spaces (S_R, S_W, etc.).

Table 1. Results of calculations

Physical quantities	Case studies A (unprovided with the attic)	Case studies B (provided with the attic)
Conditioned space volume (V)	150 m^3	120 m^3
Not-conditioned space volume (V_u)	-	30 m^3
External surfaces - conditioned space - roof (S_R)	32,28 m^2	-
External surfaces - conditioned space - walls (S_W)	124 m^2	104 m^2
External surfaces - unconditioned space - roof (S_R)	-	32,28 m^2
External surfaces - unconditioned space - walls (S_W)	-	20 m^2
Transmission heat transfer coefficient (H_T)	51,84 W/K	41,51 W/K
Direct heat transfer coefficient between the heated or cooled space and the exterior through the building envelope (H_D)	51,84 W/K	35,36 W/K
Transmission heat transfer coefficient through unconditioned spaces (H_U)	0	6,15 W/K

Direct heat transfer coefficient between the conditioned space and the unconditioned space (H_{iu})	-	9 W/K
Heat transfer coefficient between the unconditioned space and the external environment (H_{ue})	-	19,45 W/K
Ventilation heat transfer coefficient (H_V)	14,85 W/K	14,85 W/K
Heat transfer coefficient (H)	66,69 W/K	56,36 W/K

With these calculations we find that the heat transfer coefficient of our first case study (H_A) is higher than that of the second case study (H_B). We assume the same transmittance values for both case studies. In this way, we demonstrate that the heat transfer coefficient ($H=H_T+H_V$) of our building without attic is greater than that of the same building with the original attic.

5. Discussion

At this point, we can inquire about the specific conditions under which the heat loss of building without attic are lesser or greater than those of the same building provided with the attic.

In the case study A, the lack of attic implies that the surfaces are, in the worst situation, in number of 6 (four vertical walls, a floor surface at zero and a roof surface, assuming the two slopes as a single surface); while in the case study B, the surfaces are, in the worst situation, in number of 5 (four vertical walls and a floor surface at zero). In this case a new physical quantity appears H_U, the transmission heat transfer coefficient through unconditioned spaces. Let's set an inequality that allows us to find out when $H_A \le H_B$.

$$\sum_{i=1}^{6} A_i \cdot U_j + \left(\rho \cdot c_p \cdot n \cdot V_A\right) \le \sum_{i=1}^{5} A_i \cdot U_j + H_{i,u} \cdot \frac{H_{u,e}}{H_{u,i}+H_{u,e}} + \left(\rho \cdot c_p \cdot n \cdot V_B\right) \qquad (3)$$

Assuming that five surfaces are identical in the two cases (four vertical walls and a floor surface at zero), the inequality becomes:

$$A_{roof} \cdot U_{roof,A} \le A_{ceil} \cdot U_{ceil,B} \cdot \frac{A_{roof} \cdot U_{roof,B}}{A_{ceil} \cdot U_{ceil,B} + A_{roof} \cdot U_{roof,B}} + \Delta V \qquad (4)$$

where ΔV is the difference V_B - V_A.

We suppose $A_{roof} = A_{ceil} \cdot b$, where b is a function, always greater than 1, that allows us to relate the roof area with the ceiling one.

$$A_{ceil} \cdot b \cdot U_{roof,A} \le A_{ceil} \cdot U_{ceil,B} \cdot \frac{b \cdot U_{roof,B}}{U_{ceil,B} + b \cdot U_{roof,B}} + \Delta V \qquad (5)$$

Then we define a new value:

$$\gamma = \frac{U_{roof,B}}{U_{ceil,B}} \Rightarrow \gamma \cdot U_{ceil,B} = U_{roof,B} \qquad (6)$$

Therefore:

$$b \cdot U_{roof,A} \le U_{ceil,B} \cdot \frac{b \cdot \gamma \cdot U_{ceil,B}}{U_{ceil,B} + b \cdot \gamma \cdot U_{ceil,B}} + \frac{\Delta V}{A_{ceil}} \qquad (7)$$

$$U_{roof,A} \le U_{ceil,B} \cdot \frac{\gamma}{(1 + b \cdot \gamma)} + \frac{\Delta V}{A_{ceil} \cdot b} \qquad (8)$$

(9)

Where

Formula (9) let we deduce that:

- If $U_{roof,A}$ is lesser than or equal to β ( ), the solution *without attic* has a lesser thermal transmission and/or ventilation coefficient than that of the solution *with the attic*, so that it is suitable to eliminate the attic.
- If $U_{roof,A}$ is greater than β ( ), the solution *without the attic* has a greater thermal transmission and/or ventilation coefficient than that of the solution *with the attic*, so that it is unsuitable to eliminate the attic.

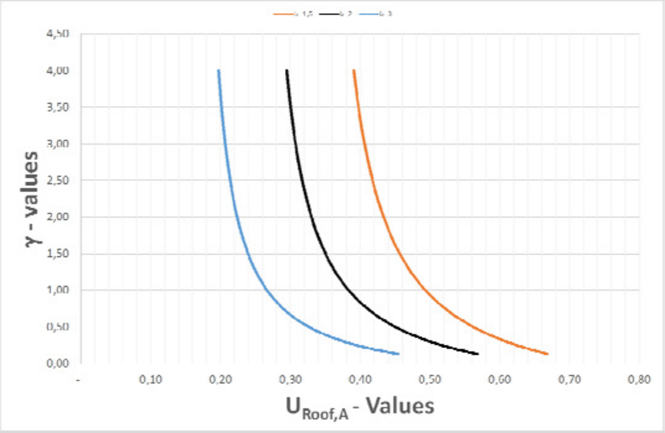

Fig. 3. Graphic relation between $U_{Roof,A}$ (x-axis) and γ values (y-axis)

6. Conclusions

We can conclude that the choice of dismantling or preserve the attic depends on the relationship between roof and ceiling transmittance values (as illustrated in Fig. 3). The present paper is just a contribution to the problem of attic conservation or dismantling in historical buildings, susceptible of integrations, even on the adopted criteria to formulate the Inequation (9). Moreover we need to study and γ values.

Concluding, we believe that the restoration project is an act of responsibility towards the existing building, and that the concept of energy saving should consist in the choice of a minor impact intervention, both from a cultural (qualitative) and an energetic (quantitative) point of view.

References

[1] D'Orazio M, Di Perna C, Di Giuseppe E. The effects of roof covering on the thermal performance of highly insulated roofs in Mediterranean climates. Energy and Buildings 42 (2010) 1619-1627.

[2] Karam M. Al-Obaidi, Mazran Ismail, Abdul Malek Abdul Rahman. A review of the potential of attic ventilation by passive and active turbine ventilators in tropical Malaysia. Sustainable Cities and Society 10 (2014) 232–240.

[3] Dimoudi A, Androutsopoulos A, Lykoudis S. Summer performance of a ventilated roof component. Energy and Buildings 38 (2006) 610–617.

[4] Ozel M, Pihtili K, Investigation of the most suitable location of insulation applying on building roof from maximum load levelling point of view, Building and Environment 42 (2007) 2360–2368.

[5] Ben-Nakhi A, Mahmoud AM, Mahmoud MA, Al Dashti A, Improving thermal performance of the roof enclosure of heavy construction buildings, Applied Energy 85 (2008) 911–930.

[6] EN ISO 13789 Thermal Performance of buildings. Transmission and ventilation heat transfer coefficients. Calculation method.