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A Comparison between On-Site Measured and Estimated Based Adjustment Factor Values Used to Calculate Heat Losses to Unconditioned Spaces in Dwellings

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Abstract: Steady-state methods have been widely used in Europe to analyse the energy performance of low-energy buildings. The accuracy of such methods depends on the assumptions regarding the compensation of non-stationary effects, but also on the input design data, such as the temperature of unconditioned spaces (UnSp). This temperature depends mainly on the thermal characteristics of UnSp envelope, air ventilation rate, temperature of the conditioned spaces and the external environment. External environment varies over time, daily and seasonally, making it difficult to accurately estimate UnSp temperature. European Union (EU) directives stated that the UnSp temperature can be evaluated by the adjustment factor (b) set by EN ISO 13789. However, each Member State may adjust procedures, by proposing simplified approaches, either for new or existing buildings. In this paper the b-values measured on-site in three dwellings were compared to those calculated by EN ISO 13789 as well as those estimated based on simplified procedures, allowed in the regulatory framework of some EU Member States, namely Ireland, Portugal, Spain, France and Italy. The study allowed to conclude that EN ISO 13789 and Irish BR 443 provided similar values. However, if the purpose is to simplify procedures and reduce computation effort, French RE2020 proved to be very effective. The thermal characteristics of the UnSp envelope and air ventilation rate were identified as the parameters that most affect the estimation of the b-value, while thermal losses through linear thermal bridges and the ground do not seem to have a significant impact.

Keywords: heat transfer; unconditioned space; adjustment factor; regulation; simplified methods; steady-state regime; buildings; thermal envelope



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1. Introduction

The United Nation Secretary-General's statement on the conclusion of the "COP26 Climate Change Conference" in Glasgow, Scotland, on 13 November 2021 [1], emphasises the urgency of strengthening measures and accelerating actions to reduce greenhouse gas emissions, which require action at a global level on various fronts. According to the European Commission's report "Clean Energy Package for all Europeans" [2], it is crucial for the clean energy transition to place a special emphasis on improving energy performance in the building sector, as buildings are the largest energy consumers, accounting for 40% of final energy consumption and 36% of greenhouse gas emissions in Europe. The International Energy Agency [3] has also identified the construction sector as one of the most cost-effective sectors for reducing energy consumption by improving energy performance, which at the same time contributes to reducing the concentration of carbon dioxide in the atmosphere. Therefore, building designers, planners and the construction industry have a huge potential to contribute towards the fight against climate change by improving the

thermal behaviour of buildings, as well as reduction of energy consumption and carbon dioxide emissions, while increasing the safety and comfort standards of its users.

To analyse the energy performance of low-energy buildings there are many available tools, from the simplest and least elaborate, used at an early design stage [4], or those used in the regulatory framework to check compliance with the energy performance requirements or carry out an energy performance certification to, finally, those more elaborate and based on dynamic simulation software, e.g., *TRNSYS* or *EnergyPlus*. There has been some discussion in recent years about the lower accuracy of steady-state methods for predicting the energy performance of low-energy buildings compared to a dynamic simulation model. In this regard, Ballarini et al. [5] have shown that steady-state calculation accuracy reduces when compared to simulation method (*EnergyPlus*) for buildings where the weight of the thermal transfer in the energy balance increases, as for nearly zero-energy buildings (NZEB). However, steady-state methods are still in use, being generally preferred to a dynamic simulation tool, due to their capability to be easily understood and manageable, the rapidity in collecting and processing input data and the consequent reduced costs for customers [5]. It is reasonable to assume that decisions about the input data, e.g., the UnSp temperature, can also affect the accuracy of the steady-state methods.

The thermal envelope of buildings results from the analysis of the use assigned to the different compartments, whether it is conditioned or unconditioned spaces (UnSp), being the thermal envelope defined as a physical barrier that surrounds all conditioned spaces at a set design internal temperature (INT). The elements of this envelope separating the INT from the external environment (EXT) are referred to as the outer envelope, while the elements separating the INT from an UnSp are referred to as the inner envelope. Through the inner envelope elements, heat transmission occurs, associated with the existing gradient of temperature between the INT and the UnSp. As the UnSp is not acclimatized, its temperature (θ_u) is between the INT (θ_i) and the EXT temperatures (θ_e). The temperature in the UnSp depends on the use and type of space (geometry, characteristics of the envelope, and ventilation, among others) and on the INT and EXT temperatures. Since the EXT temperature varies over time, daily and seasonally, it is difficult to accurately estimate the temperature of the UnSp for the purposes of energy performance analysis. However, for measurements over long periods, the non-stationary effects of temperature can be compensated for, allowing the use of average values in steady-state methods.

Some methodologies are based on the adjustment factor (b) to estimate the UnSp temperature used for energy balance effects in the heating season (winter). In this assumption, for the heating season, some simplifications are admissible and incorporated in different methodologies. The European Directive 2010/31/EU [6] as amended by Directive (EU) 2018/844 [7], stated that the adjustment factor (b) should be determined as specified by EN ISO 13789 [8]. However, each Member State may adjust procedures, by proposing simplified approaches, either for new or existing buildings. The simplified approaches may differ among European Member States, conducting to different adjustment factor (b) values, which are usually the basis to specify the minimum requirements of the inner envelope, namely the maximum admissible U-value.

To comply with new European Directives, member states updated their regulations concerning the energy performance of buildings, and some of them have revised these simplified approaches. In this sense, it is the opportunity to analyse the current situation of the simplified procedures regarding the adjustment factor (b). Some of the simplified procedures do not differentiate the thermal characteristics of either the elements separating INT from UnSp, or the elements separating UnSp from EXT, or they are inaccurate in distinguishing ventilation rates. The values calculated based on these assumptions may not reflect current building solutions and may be penalising the energy performance analysis of new buildings with better insulation conditions in the UnSp, or they may induce designers to make less appropriate decisions on which elements should be insulated.

Fundamental studies analysing and comparing the most recent proposals of simplified procedures used to estimate the adjustment factor for unconditioned spaces are scarce

in literature. In a study published in 2018, previous to the most recent EU Directives, Vučićević et al. [9] compared four different procedures to determine the adjustment factor when analysing the unheated attic of a High School in Belgrade, in order to assess the energy performance of the building. The four different procedures include: (a) on-site measurement of temperatures for 11 days; (b) calculated from Standard EN ISO 13789; (c) simplified b-values set by Servian regulation and (d) simulated by using TRNSYS software. In that study, Vučićević et al. [9] concluded that both EN ISO 13789 and dynamic simulation b-values are consistent with the measured b-value on site, and that the simplified b-value set by Serbian regulations is considerably lower than the others. They argue that such a fixed value should not be used for any roof composition as a constant, since the adjustment factor clearly depends on the roof insulation.

The present study intends to experimentally evaluate the adjustment factor (b) for three dwellings. For this purpose, the temperature profiles were acquired by using data loggers placed in conditioned spaces (INT), UnSp and in exterior (EXT) of the buildings. The measured b-value for each UnSp was compared to those obtained by using EN ISO 13789 [8], as well as those obtained by simplified methods of Irish regulation (BR 443 [10] and TGD-L [11]), Portuguese regulations (RCCTE [12], REH [13] and DEE [14]), Spanish regulation DB-HE [15], French regulation RE2020 [16] and Italian regulation UNI/TS [17]. The obtained results allowed us to compare the relative performance of the different simplified procedures to estimate the adjustment factor b-value used to quantify heat losses to UnSp.

2. Research Fundamentals and Significance

2.1. The Concept of Adjustment Factor for Unheated Spaces

In the energy performance analysis of a building, the INT temperature (θ_i) is established based on a thermal comfort reference temperature, while the EXT temperature (θ_e) is obtained from climatic data. To estimate the UnSp temperature (θ_u), some methodologies use as reference the difference between the INT and EXT temperatures, affecting it by a correction factor, called the adjustment factor (b). Equation (1) explains the significance of the b-value, which necessarily varies between 0 and 1, when θ_u is between θ_i and θ_e .

$$(\theta_i - \theta_u) = b \times (\theta_i - \theta_e) \quad (1)$$

The adjustment factor (b) is used to calculate the heat transfer associated with the thermal gradient between the INT and UnSp in the heating season (winter), as per Equation (2), where: Q is the heat flow through the inner envelope, in Wh; U_i the thermal transmittance of the inner envelope element, in $W/(m^2 \cdot K)$; A_i the area of the inner envelope element, in m^2 ; b the adjustment factor, dimensionless; θ_i the internal temperature, in $^\circ C$; and θ_e the external temperature, in $^\circ C$.

$$Q = U_i \times A_i \times b \times (\theta_i - \theta_e) \quad (2)$$

Other methodologies assume a different approach [10], considering the UnSp as an additional element with a certain thermal resistance (R_u). In this case, the heat transfer through the element separating the INT from the UnSp is calculated via Equation (3), by using the INT and EXT temperatures and assuming an adjusted thermal transmittance (U_c), which is calculated from Equation (4) or Equation (5). The value of R_u is calculated by Equation (6). The variables from Equations (3)–(6) have the following meaning: U_c is the adjusted thermal transmittance, in $W/(m^2 \cdot K)$; R_u is the effective thermal resistance of UnSp, in $m^2 \cdot K/W$ and H_{ue} is the heat transfer coefficient between the UnSp and EXT, in W/K .

$$Q = U_c \times A_i \times (\theta_i - \theta_e) \quad (3)$$

$$U_c = U_i \times b \quad (4)$$

$$U_c = \frac{1}{\frac{1}{U_i} + R_u} \quad (5)$$

$$R_u = \frac{A_i}{H_{ue}} \quad (6)$$

The methodologies for quantifying the value of b vary, from the simplest and easiest to implement, to the most complex and therefore requiring a higher processing time. To understand the scope of the simplifications, it is necessary to evaluate their effect on the energy balance in UnSp.

2.2. Energy Balance in Unheated Spaces

Figure 1 graphically illustrates the different heat exchanges that can occur in a UnSp. Unless justified, the notation presented for Figure 1 will be used in all equations presented throughout this article, avoiding their repetition. The temperature of a UnSp, as well as the respective adjustment factor (b), can be determined from the energy balance, assuming a steady-state regime with a constant flow. In general, the energy balance in an UnSp must take into account the heat exchanges that occur through the constructive elements that separate the INT from the UnSp (solid red line in Figure 1), as well as the heat exchanges through the constructive elements (e.g., walls, slabs, windows and doors) that separate UnSp from the EXT (dotted blue line in Figure 1). The simplified models used to estimate the adjustment factor normally considers some simplifications in the analysis of the energy balance, taking into account the fact that this parameter is normally used to quantify the heat transfer in the heating season.

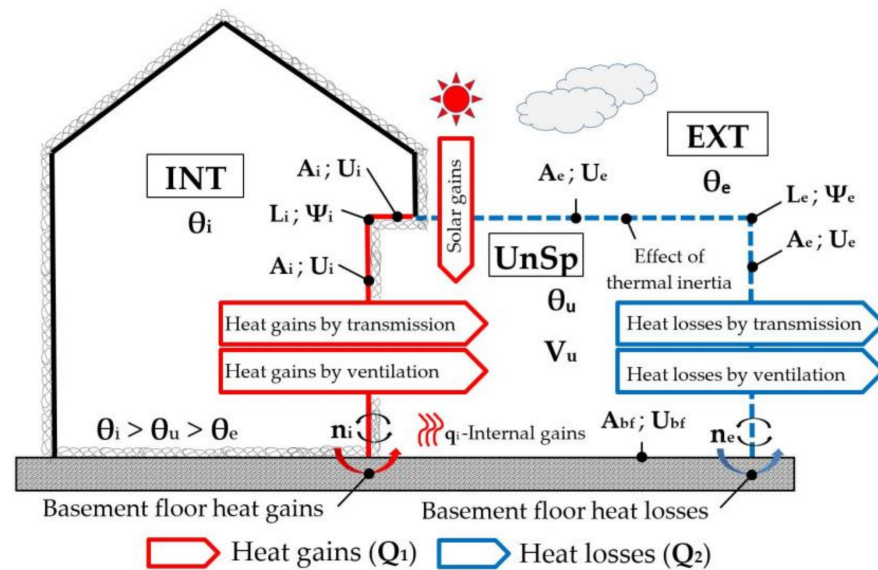


Figure 1. Schematic representation of heat exchanges in an UnSp.

Notation used in Figure 1:

Q_1 —Global thermal gains, in Wh;

Q_2 —Global thermal losses, in Wh;

θ_i —Temperature in the INT, in °C;

θ_u —Temperature in the UnSp, in °C;

θ_e —Temperature in the EXT, in °C;

U_i —Thermal transmittance of the inner envelope, in $W/(m^2 \cdot K)$;

U_e —Thermal transmittance of the outer element of UnSp, in $W/(m^2 \cdot K)$;

U_{bf} —Thermal transmittance of the basement floor of UnSp, in $W/(m^2 \cdot K)$;

Ψ_i —Linear thermal transmittance in the inner envelope, in $W/(m \cdot K)$;

Ψ_e —Linear thermal transmittance in the outer element of UnSp, in $W/(m \cdot K)$;

A_i —Area of the inner envelope element separating the INT from the UnSp, in m^2 ;
 A_e —Area of the outer element separating the UnSp from the EXT, in m^2 ;
 A_{bf} —Area of the basement floor of the UnSp, in m^2 ;
 L_i —Extent of the linear thermal bridge separating the INT from the UnSp, in m;
 L_e —Extent of the linear thermal bridge separating the UnSp from the EXT, in m;
 V_u —Volume of UnSp, in m^3 ;
 n_i —Air change rate of UnSp (by exchange with the INT), in h^{-1} ;
 n_e —Air change rate of UnSp (by exchange with the EXT), in h^{-1} .

Thermal gains in UnSp resulting from INT spaces generally include heat transfer through the elements of the interior envelope. Some methods also include heat transfer by linear thermal bridges, while thermal gains through the basement floor are neglected. Air exchanges between the INT and the UnSp are always neglected, as it is assumed that the inner envelope is airtight. None of the analysed simplified methods account for the solar radiation heat gains in the UnSp, assuming that these gains are reduced in winter. However, if the UnSp consists of a solarium, solar gains can be significant in Mediterranean climates with high sun exposure. None of the analysed methods account for internal gains in the UnSp, although in some particular situations, such as technical zones for heating boilers, these gains can even be significant, raising the temperature of the UnSp. Since gains from solar radiation or internal gains are not taken into account, neither method takes into account the effect of internal thermal inertia to account for useful gains.

In terms of thermal losses, heat transfer through the elements that separate the UnSp from the EXT are normally accounted for, and some methods also include thermal losses by linear thermal bridges. Heat transfer from basement floors and walls in contact with the ground are neglected, but the air exchange between the UnSp and EXT are normally considered. Some methods propose methodologies to estimate the air change rate of the UnSp (per air exchange with the EXT).

Global thermal gains (Q_1) are calculated using Equation (7). In this equation, H_{iu} represents the heat transfer coefficient between the INT and UnSp in W/K.

$$Q_1 = H_{iu} \times (\theta_i - \theta_u) \quad (7)$$

Global thermal losses (Q_2) are calculated using Equation (8). In this equation, H_{ue} represents the heat transfer coefficient between the UnSp and EXT in W/K.

$$Q_2 = H_{ue} \times (\theta_u - \theta_e) \quad (8)$$

In steady-state regime, with constant flow, it is assumed that Q_1 is equal to Q_2 . This equality results in Equation (9), which determines the temperature in the UnSp. The adjustment factor (b) can be calculated by Equation (10), as a function of the temperatures.

$$\theta_u = \frac{H_{iu} \times \theta_i + H_{ue} \times \theta_e}{H_{ue} + H_{iu}} \quad (9)$$

$$b = \frac{\theta_i - \theta_u}{\theta_i - \theta_e} \quad (10)$$

By replacing in Equation (10) the value of θ_u given by Equation (9), the value of b is obtained, expressed by Equation (11) as a function of the heat transfer coefficients H_{iu} and H_{ue} . In Equation (11), H_{iu} is the heat transfer coefficient between INT and UnSp, in W/K, while H_{ue} represents the heat transfer coefficient between UnSp and EXT, in W/K.

$$b = \frac{H_{ue}}{H_{ue} + H_{iu}} \quad (11)$$

Thus, the simplifications adopted in the different methods varied according to the elements considered in the evaluation of the global heat transfer coefficients H_{iu} and H_{ue} .

2.3. Simplifications in Thermal Loss Analysis for Unheated Spaces

2.3.1. EN ISO 13789

Compared to the general model shown in Figure 1, the model adopted by EN ISO 13789 [8] assumes the following simplifications: it does not take into account the solar radiation gains, nor the internal gains or, the effect of the internal thermal inertia in the UnSp. Heat transmission through the ground is not included in either H_{iu} or H_{ue} ; additionally, it assumes that there are no air exchanges between the INT and UnSp.

In the procedure of EN ISO 13789 [8], the calculation of the adjustment factor (b) is performed by using Equation (11), already described. The heat transfer coefficient (H_{iu}) includes only the transmission heat transfer coefficient ($H_{iu,tr}$), according to Equation (12), while the heat transfer coefficient (H_{ue}) includes the transmission heat transfer coefficient ($H_{ue,tr}$) and ventilation heat transfer coefficient ($H_{ue,vent}$), according to Equation (13).

$$H_{iu} = H_{iu,tr} = \sum(U_i \times A_i) + \sum(\Psi_i \times L_i) \quad (12)$$

$$H_{ue} = (H_{ue,tr} + H_{ue,vent}) \quad (13)$$

The transmission heat transfer coefficient ($H_{ue,tr}$) between UnSp and EXT is given by Equation (14), while the heat transfer coefficient between UnSp and EXT associated with ventilation ($H_{ue,vent}$) is given by Equation (15).

$$H_{ue,tr} = \sum(U_e \times A_e) + \sum(\Psi_e \times L_e) \quad (14)$$

$$H_{ue,vent} = 0.33 \times n_e \times V_u \quad (15)$$

The air change rate (n_e) in the UnSp is obtained by using Table 1. In cases where the equivalent leakage area (A_L) is known, the value of n_e to be used in Equation (15) will be the value given by Table 1 closest to the value obtained by Equation (16). In Equation (16), A_L is the area of all openings between UnSp and EXT (cm^2), while V_u represents the volume of the UnSp (m^3).

$$n_e = \frac{A_L}{10 \times V_u} \quad (16)$$

Table 1. Conventional air change rates between the UnSp and the EXT (adapted from [8]).

Airtightness Type	n_e (h^{-1})	Example of Unheated Space
No doors or windows, all joints between components well-sealed, no ventilation openings provided.	0.1	Internal Space with no external elements and no ventilation.
All joints between components well-sealed, no ventilation openings provided.	0.5	Space with external elements, windows, and doors, but well-sealed and no ventilation openings.
All joints well-sealed, small openings provided for ventilation.	1.0	Space with external elements but well-sealed and passive duct with controllable louvers between space and outside.
Not airtight, due to some localised open joints or permanent ventilation openings.	3.0	Space with external elements and wall fan with permanent opening.
Not airtight, due to numerous open joints, or large or numerous permanent ventilation openings.	10.0	Carpark with a number of permanent ventilation openings.

2.3.2. TGD-L2021

The transposition into the Irish legal order of European Directive 2010/31/EU [6] on the energy performance of buildings (recast) as amended by Directive (EU) 2018/844 [7], occurred in 2019 with the publication of the Statutory Instrument S.I. No. 183/2019 of 3rd May [18]. The procedure and requirement to account for the effect of unheated spaces on heat loss calculations is provided by the Appendix A of the Technical Guidance Document L 2021 [11].

The TGD-L2021 [11] established that the procedure for the calculation of U-values of elements adjacent to UnSp must follow the EN ISO 6946 [19] and EN ISO 13789 [8]. However, it allows for the use of simplified procedures for typical housing situations.

The simplified calculation procedure used by TGD-L [11] does not include the determination of the adjustment factor (b), instead considering the UnSp an additional element with a certain thermal resistance (R_u). The thermal loss by transmission (Q), in Wh, between the INT and the EXT, through the UnSp, is calculated by using Equation (17), with U_c being the adjusted thermal transmittance, in $W/(m^2 \cdot K)$. The U_c is given by Equation (18), where U_0 is the thermal transmittance of the element that separates the INT from the UnSp, $W/(m^2 \cdot K)$, calculated considering $R_{se} = R_{si}$; that is, U_0 has the same meaning as U_i (Figure 1). In Equation (18), R_u represents the effective thermal resistance of the UnSp, expressed in $m^2 \cdot K/W$.

$$Q = U_c \times A_i \times (\theta_i - \theta_e) \quad (17)$$

$$U_c = \frac{1}{\frac{1}{U_0} + R_u} \quad (18)$$

Basically, two different simplified procedures to estimate R_u can be distinguished in the Appendix A of TGD-L2021 [11]. The less simplified procedure follows the method described in BR 443 [10] and, for simplification, is here named BR 443. The most simplified procedure set by TGD-L2021 [11] is intended to be used when the precise details and dimensions on the elements of the unheated space are not available, or are not crucial, being here simply identified as TGD-L.

BR 443

In this procedure, the R_u can be calculated, as detailed in BR 443 [10], by using Equation (19).

$$R_u = \frac{A_i}{\sum(A_e \times U_e) + 0.33 \times n_e \times V_u} \quad (19)$$

To enable comparison with the procedure used by EN ISO 13789 [8], the model of BR 443 [10] can be presented as a function of the H_{iu} and H_{ue} coefficients. Thus, considering that H_{iu} and H_{ue} are expressed by Equations (20) and (21), respectively, the value of R_u can be expressed by Equation (22) and the value of U_c expressed by Equation (23).

$$H_{ue} = \sum(A_e \times U_e) + 0.33 \times n_e \times V_u \quad (20)$$

$$H_{iu} = A_i \times U_0 = A_i \times U_i \quad (21)$$

$$R_u = \frac{A_i}{H_{ue}} \quad (22)$$

$$U_c = \frac{U_0 \times H_{ue}}{H_{ue} + H_{iu}} \quad (23)$$

The adjustment factor is given by Equation (4). Thus, by replacing the U_c via Equation (23), the value of b is given by Equation (24), as a function of the heat transfer coefficients H_{iu} and H_{ue} .

$$b = \frac{H_{ue}}{H_{ue} + H_{iu}} \quad (24)$$

When applying BR 443 [10], the following conditions must be observed: (1) the U_c value is rounded to two decimal places if it is less than 1 and to one decimal place if it is greater than 1; (2) if the value of the thermal transmission coefficient (U_e) of the elements separating the UnSp from the EXT is not specified, BR 443 assumes by default that $U_e = 2 W/(m^2 \cdot K)$; (3) the UnSp air renewal rate (n_e) is obtained by using the same table proposed in EN ISO 13789 (Table 1) and if the UnSp conditions that allow the use of Table 1 are not known, a default n_e of $3 h^{-1}$ is assumed and (4) if the impact of the adjustment is negligible, the calculation of U_c can be ignored, as in the situations indicated in Table 2.

Table 2. Application of the adjusted U value (adapted from [10]).

Value of U_0 (W/(m ² ·K))	$\left(\frac{U_c - U_0}{U_0} \times 100\right)^*$
<1	The adjustment is not made if $\leq 10\%$
1 to 3	The adjustment is not made if $\leq 5\%$
>3	The adjustment is always done
(*) It can also be expressed by: $((1 - b) \times 100)$	





Comparing with the general model shown in Figure 1, the BR 443 [10] assumes the following simplifications: it does not take into account the solar radiation gains, internal gains, or internal thermal inertia in the UnSp. On the other hand, it assumes that there are no air exchanges between the INT and UnSp and disregards the heat losses through the ground floor and losses due to linear thermal bridges in the UnSp. Even so, it considers the thermal transmittance of the elements of the UnSp and takes into account the air renewal rate of UnSp. Compared with EN ISO 13789 [8], it can be seen that neither linear thermal losses nor losses through the ground floor are considered.

TGD-L

In this procedure the R_u is simply obtained from Tables 3–5 for typical UnSp (including garages, access corridors to flats and conservatories/sunroom). The Equation (25) can be used to calculate the adjustment factor (b), thus allowing for comparison with the other methods analysed in this research work. In Equation (25), the U_0 is the thermal transmittance of the element that separates the INT from the UnSp and has the same meaning as U_i (Figure 1).

$$b = \frac{1}{1 + U_0 \times R_u} \quad (25)$$

Table 3. Typical R_u values for integral and adjacent single garages or other similar UnSp (adapted from [11]).

UnSp	Element between the Garage and the Dwelling	Typical Resistance (R_u)	
		Outside ¹	Inside ²
	Side wall, end wall and floor	0.33	0.68
	One wall and floor	0.25	0.54
	Side wall, end wall and floor	0.26	0.56
	One wall	0.09	—

Notes: The table gives R_u for single garages use ($0.5 \times R_u$) for double garages when extra garage is not fully integral and ($0.85 \times R_u$) for fully integral double garages. Single garage means a garage for one car; double garage means a garage for two cars. ¹ Walls separating garage from dwelling are external walls; ² insulated envelope of dwelling goes round outside of garage.

Table 4. Typical R_u values for conservatory-type sunroom (adapted from [11]).

Number of Walls between Dwelling and Conservatory/Sunroom	Typical Resistance (R_u)
One	0.06
Two (conservatory in angle of dwelling)	0.14
Three (conservatory in recess)	0.25

Table 5. Typical R_u values for unheated stairwells and access corridors in flats (adapted from [11]).

Type of Unheated Space (UnSp)		Typical Resistance (R_u)
Stairwells:	—Facing wall exposed	0.82
	—Facing wall not exposed	0.90
Access corridors:	—Facing wall exposed, corridor above or below	0.31
	—Facing wall exposed, corridor above and below	0.28
	—Facing wall not exposed, corridor above or below	0.43
	—Facing wall not exposed, corridor above and below	0.40

2.3.3. RCCTE

In 2002, the European Union approved the Directive 2002/91/EC [20] of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings (EPBD). This directive establishes a common reference for the countries of the Union regarding the energy performance of buildings, quantification of energy needs, CO₂ emission rate and energy classification. In 2006, the Directive 2002/91/EC was transposed into the Portuguese national legal system. The energy performance of residential buildings became regulated in Portugal by Decree-Law no. 80/2006 of 4 April [12], which became known in Portugal as the Regulation of Thermal Behaviour Characteristics of Buildings, RCCTE:2006 [12]. Currently, this regulation is no longer in force, but the values of the determination of b are important for understanding the simplifications that have been adopted in the last decade. This regulation proposes the b -values shown in Table 6, differentiated by the type of UnSp and considering only three parameters: the volume of the UnSp, ventilation of the UnSp and ratio between the areas of the envelope of the UnSp (A_i/A_e). Comparing with the general model described in Figure 1, the RCCTE:2006 [12] assumes the following simplifications: it does not take into account the gains from solar radiation, internal gains, or internal thermal inertia in the UnSp. On the other hand, it assumes that there are no air exchanges between the INT and UnSp and does not consider thermal losses by the ground floor, thermal losses by linear thermal bridges, or thermal losses by transmission in the building envelope elements of the UnSp.

Table 6. Values for the adjustment factor (b), set by the RCCTE:2006 (adapted from [12]).

Type of Unheated Space	A_i/A_e		
	<1	1 to 10	>10
1- Common circulation spaces:			
1.1- With no direct opening to the outside	0.6	0.3	0
1.2- With a permanent opening to the outside (1)			
(a) Permanent openings area/total volume < 0.05 m ² /m ³	0.8	0.5	0.1
(b) Permanent openings area/total volume ≥ 0.05 m ² /m ³	0.9	0.7	0.3
2- Commercial spaces	0.8	0.6	0.2
3- Adjacent buildings	0.6	0.6	0.6
4- Warehouses	0.95	0.7	0.3
5- Garages:			
5.1- Private	0.8	0.5	0.3
5.2- Collective	0.9	0.7	0.4
5.3- Public	0.95	0.8	0.5
6- Balconies, marquees and similar spaces	0.8	0.6	0.2
7- Uninhabited attic (accessible or not):			
7.1- Unventilated: ventilation openings area/attic area is less or equal than 500 mm ² /m ²	0.8	0.6	0.4
7.2- Poorly ventilated: ventilation openings area/attic area is higher than 500 and less or equal than 1500 mm ² /m ²	0.9	0.7	0.5
7.3- Strongly ventilated: ventilation openings area/attic area is greater than 1500 mm ² /m ²	1	1	1

A_i is the area of all elements that separates the INT from the UnSp. A_e is the area of all elements that separates the UnSp from the EXT. ⁽¹⁾ For example, for ventilation or smoke clearance.

2.3.4. REH/DEE

In 2010, the Directive 2002/91/EC [20] has been amended by European Union by approving the Directive 2010/31/EU [6] of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (Recast EPBD). This new Directive clarifies the common general framework for the methodology for calculating the energy performance of buildings and reinforces the measures of Directive 2002/91/EC regarding the improvement of the energy performance of buildings, aiming at the goals and challenges agreed by the Member States for 2020. In 2013 the Directive 2010/31/EU was transposed into the Portuguese national legal order. The energy performance of residential buildings becomes regulated in Portugal by Decree-Law no. 118/2013 of 20 August [13] and other complementary legislation that make it operational. In the case of residential buildings, it was renamed to Regulation on the Energy Performance of Residential Buildings, REH:2013 [13].

In 2016, the European Commission presented the Clean Energy Package for all Europeans [2], with a view to establishing the necessary practical and regulatory framework for the energy transition in the 2021–2030s. The Clean Energy Package includes amendments to Directive 2010/31/EU [6]. In 2018, the European Union approved the Directive (EU) 2018/844 [7] of the European Parliament and Council of 30 May 2018, amending Directive 2010/31/EU [6] on the energy performance of buildings, as well as Directive 2012/27/EU [21] on energy efficiency. In 2019, the European Union approved the Directive (EU) 2019/944 [22] of the European Parliament and of the Council, of 5 June 2019, on common rules for the internal market for electricity and amending Directive 2012/27/EU (recast). In 2020, the Directive (EU) 2018/844 [7] and, partially, the Directive (EU) 2019/944 [22], were transposed to the Portuguese national legal system, through the publication of Decree-Law no. 101-D/2020, of 7 December [23], with the amendments incorporated by Decree-Law no. 102/2021, of 19 November [24]. This new regulation is embodied in the energy certification system (SCE) manual, here named DEE:2021 [14]. Despite these changes, the roles regarding simplified adjustment factor in DEE [14] are the same as for REH [13].

Given the difficulty in accurately knowing the temperature value in the UnSp (θ_u), REH/DEE [13,14] admits that for some types of UnSp, conventional values can be assumed, without prejudice of a more accurate calculation based on EN ISO 13789 [8]. Conventional values of b are defined in two situations: elements in contact with adjacent buildings ($b = 0.60$) and elements in contact with UnSp (Table 7). The estimate, based on Table 7, does not differentiate the type of UnSp and considers only three parameters: the volume of the UnSp, ventilation of the UnSp, and ratio between the areas of the envelope of the UnSp (A_i/A_e). Comparing to the previously applied RCCTE [12], it can be seen that the procedure was even more simplified, especially the ventilation rate, which is based on a qualitative, subjective, and inaccurate appreciation.

Table 7. Values for the adjustment factor (b), set by the REH/DEE (adapted from [13,14]).

A_i/A_e	$V_u \leq 50 \text{ m}^3$		$50 \text{ m}^3 < V_u \leq 200 \text{ m}^3$		$V_u > 200 \text{ m}^3$	
	f	F	f	F	f	F
$A_i/A_e < 0.5$	1.0	1.0	1.0	1.0	1.0	1.0
$0.5 \leq A_i/A_e < 1$	0.7	0.9	0.8	1.0	0.9	1.0
$1 \leq A_i/A_e < 2$	0.6	0.8	0.7	0.9	0.8	1.0
$2 \leq A_i/A_e < 4$	0.4	0.7	0.5	0.9	0.6	0.9
$A_i/A_e \geq 4$	0.3	0.5	0.4	0.8	0.4	0.8

Notes: For strongly ventilated spaces, i.e., (vent hole area)/(wall or roof area) is greater than $1500 \text{ mm}^2/\text{m}^2$, b assumes the value of 1.0; f—unheated space (UnSp), which has all connections between elements well-sealed, without permanently ventilation openings; F—unheated space (UnSp) permeable to air, due to the presence of permanently open connections and ventilation openings; A_i —the sum of the areas of the elements that separate the INT from the UnSp; A_e —the sum of the areas of the elements that separate the UnSp from the EXT; V_u —volume of the unheated space (UnSp) in m^3 .

2.3.5. DB-HE

European Directive 2010/31/EU [6] on the energy performance of buildings establishes the obligation of European Member State countries to review and update the minimum energy performance requirements on a regular basis, at intervals not exceeding five years, to adapt them to technical developments in the building sector. On this basis, the Spanish government proceeds to a new revision of the Technical Building Code and Basic Document on Energy Saving, by publishing the Royal Decree 732/2019, 20 December 2019 [25]. This revision introduces changes in the structure of the basic requirements to adapt them to European regulations, revises the minimum energy performance values that buildings must meet and updates the definition of a nearly zero energy building. Of relevance to this article is Section HE1 (Conditions for the control of energy demand) included in the Basic Document on Energy Saving DB-HE [15].

The document supporting the application of the Spanish regulation, DA-DB-HE1 [26], published in 2020, describes several simplified methods that can be used to calculate the characteristic parameters of the different elements of the building's thermal envelope, which does not preclude the use of other proven methods, whether simplified or detailed. This section considers the case of any interior partition in contact with a non-habitable space that, in turn, is in contact with the outside. For interior partitions (except floors in contact with sanitary chambers, which are treated separately), the adjustment factor b for adjacent non-habitable spaces (storage rooms, pantries, and adjacent garages, among others) and unconditioned spaces under sloping roofs can be obtained from Table 8, depending on the thermal insulation of the partitions of UnSp, degree of ventilation of the UnSp and relationship between the areas (A_i/A_e). This standard describes a procedure quite similar to the Portuguese standard, but with a higher detail on (A_i/A_e) parameter, as well as a higher detail in airtightness level and distinguishing the isolation situations of the UnSp partitions between the INT and UnSp and the UnSp and EXT. On the other hand, the Spanish standard does not consider the UnSp volume.

Table 8. Values for the adjustment factor (b) set by the DB-HE (adapted from [26]).

A_i/A_e	Thermal Insulation Condition of the Partition between the INT and UnSp and the UnSp and EXT					
	INT to UnSp (Insulated) and UnSp to EXT (Not Insulated)		INT to UnSp (Not Insulated) and UnSp to EXT (Not Insulated)		INT to UnSp (Not Insulated) and UnSp to EXT (Insulated)	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
$A_i/A_e < 0.25$	0.99	1.00	0.94	0.97	0.91	0.96
$0.25 < A_i/A_e \leq 0.50$	0.97	0.99	0.85	0.92	0.77	0.90
$0.50 < A_i/A_e \leq 0.75$	0.96	0.98	0.77	0.87	0.67	0.84
$0.75 < A_i/A_e \leq 1.00$	0.94	0.97	0.70	0.83	0.59	0.79
$1.00 < A_i/A_e \leq 1.25$	0.92	0.96	0.65	0.79	0.53	0.74
$1.25 < A_i/A_e \leq 2.00$	0.89	0.95	0.56	0.73	0.44	0.67
$2.00 < A_i/A_e \leq 2.50$	0.86	0.93	0.48	0.66	0.36	0.59
$2.50 < A_i/A_e \leq 3.00$	0.83	0.91	0.43	0.61	0.32	0.54
$A_i/A_e > 3$	0.81	0.90	0.39	0.57	0.28	0.50

Notes: Case 1—slightly ventilated space, which includes those spaces with a tightness level 1, 2 or 3 of Table 9; Case 2—highly ventilated space, comprising those spaces with a level of tightness 4 or 5 of Table 9; A_i —the sum of the areas of the elements that separate the INT from the UnSp; A_e —the sum of the areas of the elements that separate the UnSp from the EXT.

Table 9. Air renewal rate between non-habitable spaces and the exterior, set by the DB-HE (adapted from [26]).

Airtightness Level	n_e (h^{-1})
1. No doors, windows, or ventilation openings	0.0
2. All components sealed, without ventilation openings	0.5
3. All components well-sealed, small ventilation openings	1.0
4. Poorly sealed, due to open joints or the presence of permanent ventilation openings	5.0
5. Poorly sealed, numerous open joints, as well as large or numerous permanent ventilation openings	10.0

2.3.6. RE2020

The new French regulation, named RE2020 [27], concerning the energy and environmental performance requirements of building constructions is regulated by the Decree No. 2021-1004 of July 29, 2021 [27], and resulted from the implementation of the Directives 2010/31/EU [6] and 2018/844/EU [7] of the European Union. The RE2020 [27] apply from 1 January 2022 to the construction of buildings or parts of buildings for residential use, and subsequently, throughout 2022, to the other types of buildings. The methods and procedures applicable to the energy performance diagnosis established by the Order of 31 March 2021 [16] are of special relevance in this article, thus describing the calculation method 3CL-DPE-2021.

The calculation method 3CL-DPE-2021 states that the adjustment factor b should be preferably determined according to EN ISO 13789 [8]. However, in the absence of any particular justification, default values are allowed to be used as given in Table 10, depending on the ratio of the areas (A_i/A_e) and equivalent area coefficient ($U_{V,ue}$), as given by Table 11 for the case of dwellings (other values are provided for collective housing and tertiary buildings, but were not presented here). Coefficient $U_{V,ue}$ represents the air exchange losses of the unheated room, reduced to the unit area of the wall. The method provides for the situation of the existence or absence of isolation, both in the partition elements separating UnSp from EXT and in those separating INT from UnSp.

Table 10. Values for the adjustment factor (b), set by the RE2020 (adapted from [16]).

(a) INT to UnSp: Insulated; UnSp to EXT: Not Insulated							(b) INT to UnSp: Not Insulated; UnSp to EXT: Not Insulated						
Ai/Ae	Equivalent area coefficient $U_{V,ue}$ (Table 11)						Ai/Ae	Equivalent area coefficient $U_{V,ue}$ (Table 11)					
	0.00	0.30	1.50	3.00	7.00	9.00		0.00	0.30	1.50	3.00	7.00	9.00
≤ 0.25	0.95	0.95	1.00	1.00	1.00	1.00	≤ 0.25	0.80	0.85	0.85	0.90	0.95	0.95
$0.25 < \leq 0.50$	0.95	0.95	0.95	0.95	1.00	1.00	$0.25 < \leq 0.50$	0.65	0.75	0.75	0.80	0.85	0.90
$0.50 < \leq 0.75$	0.90	0.95	0.95	0.95	0.95	1.00	$0.50 < \leq 0.75$	0.55	0.65	0.70	0.75	0.80	0.85
$0.75 < \leq 1.00$	0.85	0.90	0.90	0.95	0.95	0.95	$0.75 < \leq 1.00$	0.50	0.55	0.60	0.70	0.75	0.80
$1.00 < \leq 1.25$	0.85	0.90	0.90	0.90	0.95	0.95	$1.00 < \leq 1.25$	0.45	0.50	0.55	0.65	0.70	0.80
$1.25 < \leq 2.00$	0.80	0.80	0.85	0.90	0.90	0.95	$1.25 < \leq 2.00$	0.35	0.40	0.45	0.50	0.60	0.70
$2.00 < \leq 2.50$	0.75	0.80	0.80	0.85	0.90	0.90	$2.00 < \leq 2.50$	0.30	0.35	0.40	0.45	0.55	0.65
$2.50 < \leq 3.00$	0.70	0.75	0.80	0.85	0.90	0.90	$2.50 < \leq 3.00$	0.25	0.30	0.35	0.40	0.50	0.60
$3.00 < \leq 3.50$	0.65	0.75	0.75	0.80	0.85	0.90	$3.00 < \leq 3.50$	0.20	0.30	0.30	0.40	0.50	0.55
$3.50 < \leq 4.00$	0.65	0.70	0.75	0.80	0.85	0.90	$3.50 < \leq 4.00$	0.20	0.25	0.30	0.35	0.45	0.50
$4.00 < \leq 6.00$	0.55	0.60	0.65	0.70	0.80	0.85	$4.00 < \leq 6.00$	0.15	0.20	0.20	0.25	0.35	0.40
$6.00 < \leq 8.00$	0.45	0.55	0.60	0.65	0.75	0.80	$6.00 < \leq 8.00$	0.10	0.15	0.15	0.20	0.30	0.35
$8.00 < \leq 10.0$	0.40	0.50	0.50	0.60	0.70	0.75	$8.00 < \leq 10.0$	0.10	0.10	0.15	0.20	0.25	0.30
$10.0 < \leq 25.0$	0.35	0.40	0.45	0.50	0.60	0.70	$10.0 < \leq 25.0$	0.05	0.10	0.10	0.15	0.20	0.25
$25.0 < \leq 50.0$	0.20	0.25	0.30	0.35	0.45	0.50	$25.0 < \leq 50.0$	0.05	0.05	0.05	0.05	0.10	0.15
$50.0 <$	0.10	0.15	0.15	0.20	0.25	0.30	$50.0 <$	0.00	0.00	0.00	0.05	0.05	0.05
(c) INT to UnSp: not insulated; UnSp to EXT: insulated							(d) INT to UnSp: insulated; UnSp to EXT: insulated						
Ai/Ae	Equivalent area coefficient $U_{V,ue}$ (Table 11)						Ai/Ae	Equivalent area coefficient $U_{V,ue}$ (Table 11)					
	0.00	0.30	1.50	3.00	7.00	9.00		0.00	0.30	1.50	3.00	7.00	9.00
≤ 0.25	0.35	0.50	0.60	0.65	0.75	0.85	≤ 0.25	0.80	0.90	0.90	0.95	0.95	0.95
$0.25 < \leq 0.50$	0.20	0.35	0.45	0.50	0.60	0.70	$0.25 < \leq 0.50$	0.65	0.80	0.85	0.85	0.90	0.95
$0.50 < \leq 0.75$	0.15	0.25	0.35	0.40	0.50	0.65	$0.50 < \leq 0.75$	0.55	0.70	0.75	0.80	0.85	0.90
$0.75 < \leq 1.00$	0.15	0.20	0.25	0.35	0.40	0.55	$0.75 < \leq 1.00$	0.50	0.65	0.70	0.75	0.85	0.90
$1.00 < \leq 1.25$	0.10	0.15	0.25	0.30	0.35	0.50	$1.00 < \leq 1.25$	0.45	0.60	0.65	0.75	0.80	0.90
$1.25 < \leq 2.00$	0.05	0.10	0.15	0.20	0.25	0.40	$1.25 < \leq 2.00$	0.35	0.45	0.55	0.65	0.70	0.80
$2.00 < \leq 2.50$	0.05	0.10	0.15	0.15	0.20	0.35	$2.00 < \leq 2.50$	0.30	0.40	0.50	0.55	0.65	0.80
$2.50 < \leq 3.00$	0.05	0.10	0.10	0.15	0.20	0.30	$2.50 < \leq 3.00$	0.25	0.35	0.45	0.55	0.60	0.75
$3.00 < \leq 3.50$	0.05	0.05	0.10	0.10	0.15	0.25	$3.00 < \leq 3.50$	0.20	0.35	0.40	0.50	0.60	0.70
$3.50 < \leq 4.00$	0.05	0.05	0.10	0.10	0.15	0.25	$3.50 < \leq 4.00$	0.20	0.30	0.40	0.45	0.55	0.70
$4.00 < \leq 6.00$	0.00	0.05	0.05	0.05	0.10	0.20	$4.00 < \leq 6.00$	0.15	0.25	0.30	0.35	0.45	0.60
$6.00 < \leq 8.00$	0.00	0.05	0.05	0.05	0.10	0.15	$6.00 < \leq 8.00$	0.10	0.20	0.25	0.30	0.40	0.55

Table 10. *Cont.*

8.00 < ≤ 10.0	0.00	0.05	0.05	0.05	0.05	0.10	8.00 < ≤ 10.0	0.10	0.15	0.20	0.25	0.35	0.45
10.0 < ≤ 25.0	0.00	0.00	0.05	0.05	0.05	0.10	10.0 < ≤ 25.0	0.05	0.10	0.15	0.20	0.25	0.40
25.0 < ≤ 50.0	0.00	0.00	0.00	0.00	0.00	0.05	25.0 < ≤ 50.0	0.05	0.05	0.10	0.10	0.15	0.25
50.0 <	0.00	0.00	0.00	0.00	0.00	0.00	50.0 <	0.00	0.05	0.05	0.05	0.05	0.10

Notes: Intermediate values can be obtained by linear interpolation; A_e of verandas should be considered as uninsulated.

Table 11. Default values of the coefficient $U_{V,ue}$ for dwellings (adapted from [16]).

Typical Unheated Spaces in Dwellings	$U_{V,ue}$
Garage, cellar, and veranda	3
Attic: —Strongly ventilated: $A_o/A_c > 0.003$	9
—poorly ventilated: $0.0003 < A_o/A_c < 0.003$	3
—very poorly ventilated: $A_o/A_c < 0.0003$	0.3

A_o is the total area of the roof ventilation openings in m^2 ; A_c is the area of the roof in m^2 .

2.3.7. UNI/TS

Through the publication of the Decree No. 48 of 10 June 2020 [28], Italy has implemented the Directive (EU) 2018/844 [7]. The calculation method to determine the adjustment factor b is defined in Technical Specification UNI/TS 11300-1 [17].

According to the Technical Specification UNI/TS 11300-1 [17], the adjustment factor b should be determined as specified in EN ISO 13789 [8]. However, for existing buildings, in the absence of reliable design data, or any case of less accurate information, the simplified values of factor b , given in Table 12, can be used.

Table 12. Simplified values for the adjustment factor (b), set by UNI/TS (adapted from [17]).

Unheated Space (UnSp)	b
Unheated Space with an external wall	0.4
Unheated Space without external windows and doors and with at least two external walls	0.5
Unheated Space with external doors and windows and at least two external walls (e.g., garages)	0.6
Unheated Space with three external walls (e.g., external stairwells)	0.8
Cellar or semi-basement without windows or external frames	0.5
Cellar or semi-basement with external windows or door frames	0.8
Attic with high ventilation rate without felt or board cladding (e.g., discontinuous covering materials)	1.0
Attic with non-insulated roof of other type	0.9
Attic with insulated roof	0.7
Internal circulation areas without external walls and with an air exchange rate lower than $0.5 h^{-1}$	0.0
Freely ventilated interior circulation areas (ratio of opening area to room volume greater than $0.005 m^2/m^3$)	1.0

3. Materials and Methods

For the present study, three single-family dwellings were selected, incorporating one or more unconditioned spaces. The houses are located in the central region of Portugal, integrated in the territorial unit Cova da Beira, and characterized by a Mediterranean climate. For each of them, the temperature profiles inside, outside, and in the unconditioned spaces were recorded. This evaluation allowed to obtain the value of the on-site adjustment factor. The elements of the thermal envelope and UnSp were also characterized to allow the estimation of the adjustment factor based on the simplified methods.

3.1. Case Study 1

Case study 1 comprises of a two-storey single-family house (Figure 2), built in 2008, when the RCCTE [12] was in force in Portugal. The building is in the municipality of Covilhã, at an altitude of 615 m, on a site with a predominance of granite residual soil. The ground floor is for housing (living room, kitchen, pantry, office, and toilets) and has an adjoining garage, while the first floor is for housing only (three bedrooms and toilets).

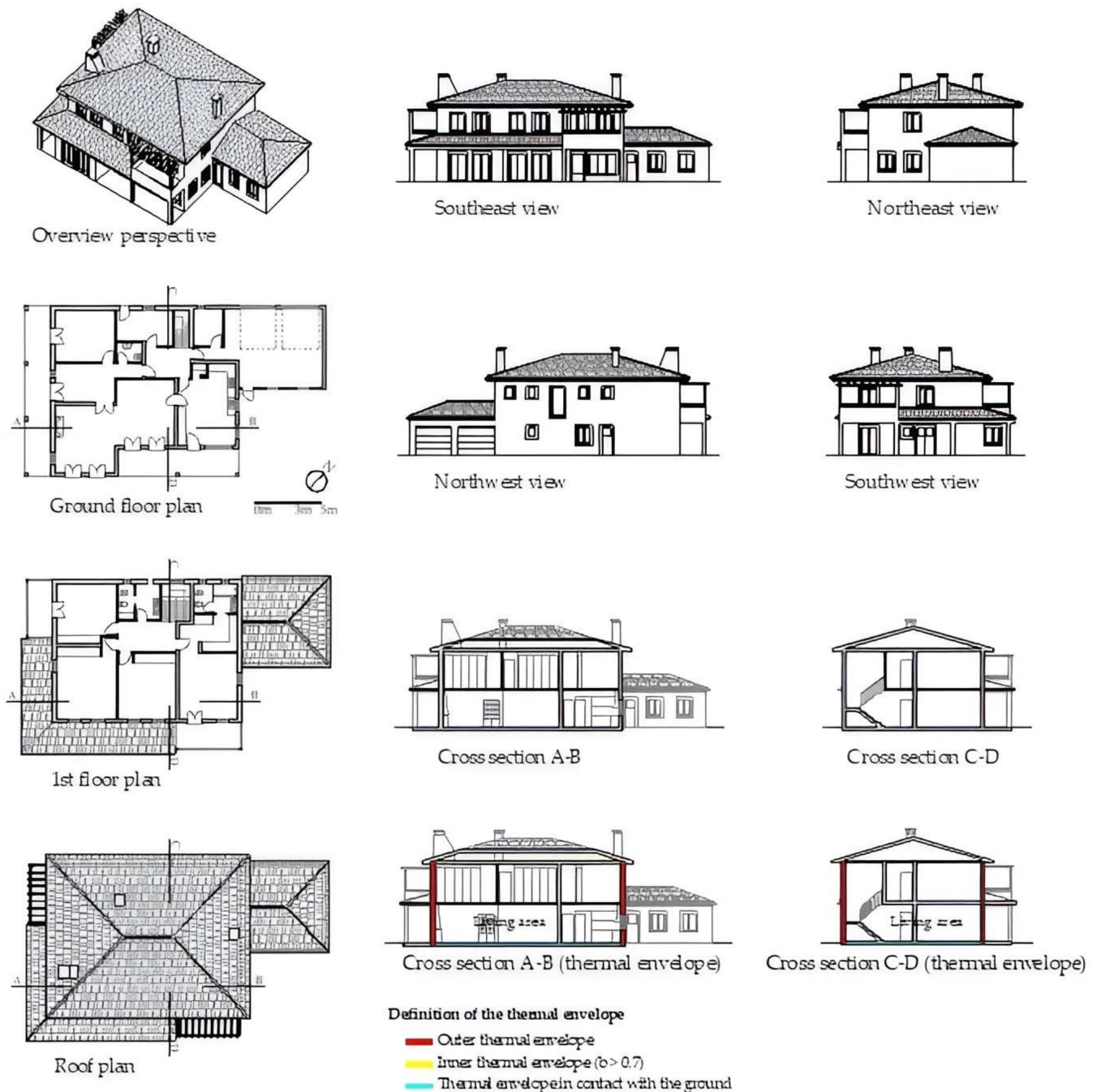


Figure 2. Case Study 1.

The building has a non-accessible attic on the roof, not air-conditioned, not compartmentalized. The exterior walls consist of double masonry of 11 cm and 15 cm thick hollow clay brick, with a 7 cm air gap, partially filled with 5 cm of extruded polystyrene (XPS), plastered on the outside with 2.5 cm of mortar and 1.5 cm stucco in interior face. The horizontal slab that separates the INT from the attic is a lightened slab type with prefabri-

cated pre-stressed concrete beams and ceramic vaults a total of 19 cm thick, with 2 cm of traditional stucco on the lower side and 3 cm of XPS on the upper side. The sloping roof slab is lightened slab type with prefabricated pre-stressed concrete beams and expanded polystyrene (EPS) vaults, a total of 19 cm thick, uncoated on the lower face, and cement tile roof on its upper face. The glazed openings are made of wood/aluminium frames with double glazing and an interior protection in dark coloured wooden shutters. The climate control in the heating season is carried out through air conditioning (heat pump), with interior splits arranged in the living room, kitchen, and bedrooms. The operation of the air conditioning is intermittent, being activated only at certain hours of the day. The ventilation of heated spaces (INT) takes place naturally through the façade openings. The attic (hereafter identified as Attic 1) is considered poorly ventilated, since it has a total of eight small ventilation holes through ventilation tiles uniformly distributed, totalizing a rough estimated opening area of 320 cm².

In Figure 2, when defining the thermal envelope, the following notations for the colouring of the partitions were used, based on the Portuguese regulation REH/DEE [13,14]: red colour for outer envelope elements (subject to minimum outer envelope requirements), yellow colour for inner envelope elements with $b > 0.7$ (subject to the same minimum requirements as the outer envelope), blue colour for inner envelope elements with $b \leq 0.7$ (subject to minimum inner envelope requirements); cyan for elements in contact with the ground (subject to specific requirements) and green for elements without thermal requirements. The same notation was used further on for Case Studies 2 and 3. Other countries may use different colours to identify the thermal envelope elements. In general, for each element of the envelope, the minimum requirements are set in terms of U-value, which depend on the climate zones and type of element under analysis.

Figure 3 shows the envelope constructive details of the unheated space (Attic 1), while Table 13 presents the geometric characteristics and physical properties of such elements, necessary to quantify the value of b by the simplified calculation methods. Thermal transmittance (U-value) was calculated according to EN ISO 6946 [19], while the linear thermal transmittance (Ψ -value) was estimated based on thermal bridge catalogues, in accordance with EN ISO 14683 [29] using the methodology defined in EN ISO 10211 [30]. The same procedure for evaluating physical properties was applied to the other case studies.

Table 13. Geometric and physical characteristics of the Attic 1.

Volume	Vent *	Elements That Separate INT from UnSp				Elements That Separate UnSp from EXT			
		U_{i1} W/(m ² ·K)	A_{i1} m ²	Ψ_{i1} W/(m·K)	L_{i1} m	U_{e1} W/(m ² ·K)	A_{e1} m ²	Ψ_{e1} W/(m·K)	L_{e1} m
V_u m ³	n_e h ⁻¹								
79.32	0.50	0.75	128.40	1.00	45.71	0.33	148.30	1.00	34.30

* Since the equivalent leakage area is known (320 cm²), the air change rate, n_e , is given by the value of Table 1 that is closest to the value obtained by Equation (16).

To obtain the temperature profiles, four battery-powered data loggers equipped with a temperature probe (Easylog EL-GFX-2) were used. Two data loggers were placed on the second floor of the housing (INT), with one in the attic (UnSp) and one outside (EXT), protected from direct solar radiation. All equipment was programmed to record the temperature at 15-minute intervals in a synchronized way, from 13th February to 3rd March.

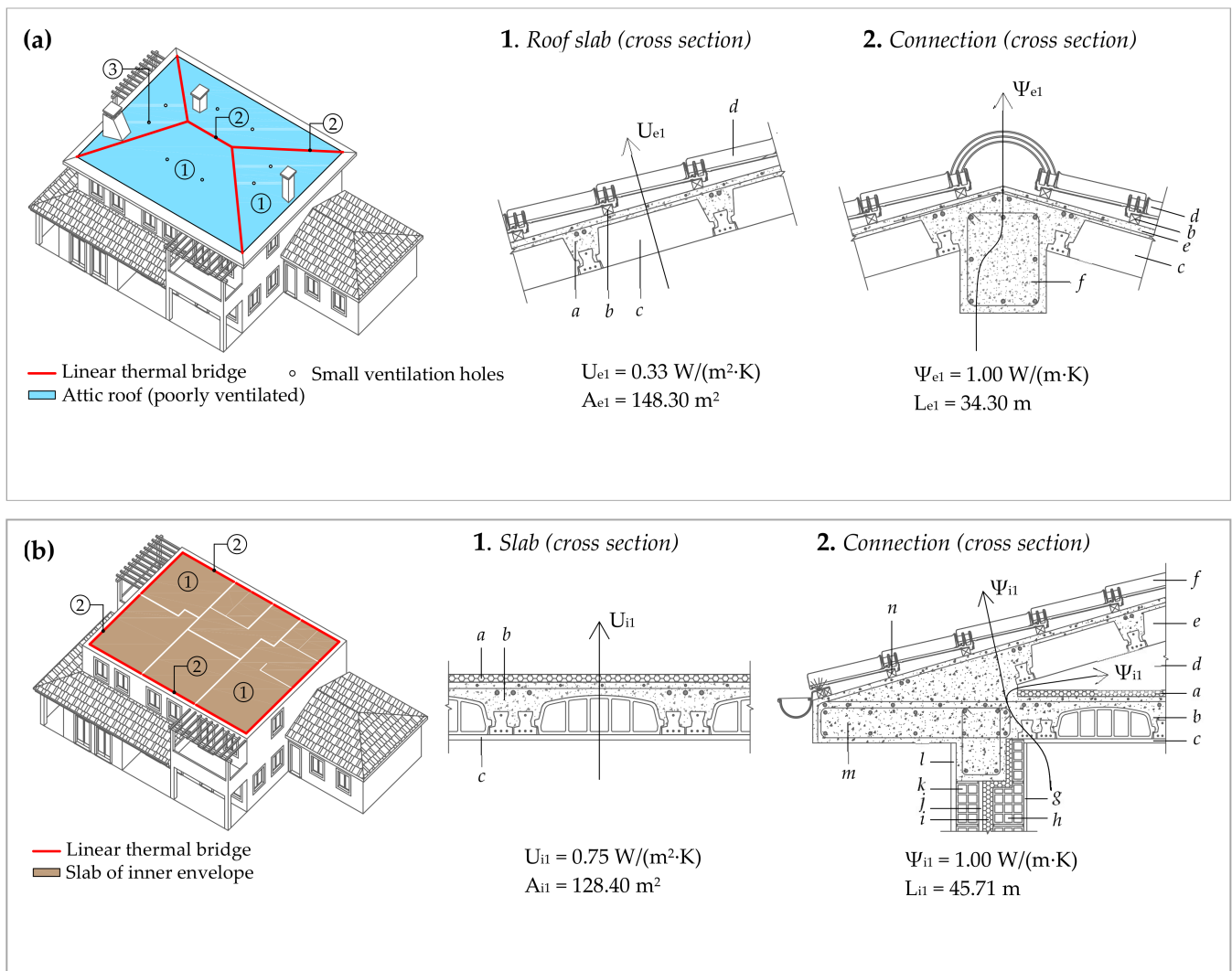


Figure 3. Characterization of the thermal envelope of Attic 1: (a) the sloping roof slab separating the attic (UnSp) from the exterior environment (EXT): **Note 1:** No scale; **Note 2:** (a) and (c) form the lightened slab with prefabricated pre-stressed concrete beams and expanded polystyrene (EPS) vaults ($R_{asc} = 2.85 \text{ m}^2\cdot\text{K}/\text{W}$); (b) PVC strips (the space immediately below the ceramic tiles is considered strongly ventilated); (d) grey cement tile roof; (e) concrete layer (4 cm); (f) reinforced concrete with $\lambda = 2.3 \text{ W}/(\text{m}\cdot\text{K})$. (b) the horizontal slab that separates the interior (INT) from the attic (UnSp): **Note 1:** No scale; **Note 2:** (a) Extruded polystyrene (3 cm) with $\lambda = 0.037 \text{ W}/(\text{m}\cdot\text{K})$; (b) lightened slab with prefabricated pre-stressed concrete beams and ceramic vaults with a total of 19 cm thick ($R_{asc} = 0.27 \text{ m}^2\cdot\text{K}/\text{W}$); (c) traditional stucco (2 cm) with $\lambda = 0.40 \text{ W}/(\text{m}\cdot\text{K})$; (d) attic space; (e) lightened slab with prefabricated pre-stressed concrete beams and expanded polystyrene (EPS) vaults ($R_{asc} = 2.85 \text{ m}^2\cdot\text{K}/\text{W}$); (f) grey cement tile roof; (g) traditional stucco (1.5 cm) with $\lambda = 0.40 \text{ W}/(\text{m}\cdot\text{K})$; (h) hollow clay brick (15 cm) with $R = 0.39 \text{ m}^2\cdot\text{K}/\text{W}$; (i) extruded polystyrene (5 cm) with $\lambda = 0.037 \text{ W}/(\text{m}\cdot\text{K})$; (j) non-ventilated air gap (2 cm) with $R = 0.175 \text{ m}^2\cdot\text{K}/\text{W}$; (k) hollow clay brick (11 cm) with $R = 0.27 \text{ m}^2\cdot\text{K}/\text{W}$; (l) traditional rendering mortar (2.5 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (m) reinforced concrete; (n) PVC strips (the space immediately below the ceramic tiles is considered strongly ventilated).

3.2. Case Study 2

Case Study 2 comprises a two-storey single-family house (Figure 4), built in the 80s of the 20th century, when in Portugal there were still no regulations for the energy performance of buildings. The building is in the municipality of Fundão, at an altitude of 511 m, on a site with a predominance of granite residual soil. The ground floor is for the garage (hereafter identified as Garage 1), while the first floor is for housing, including the living room, kitchen, two bedrooms and a bathroom.

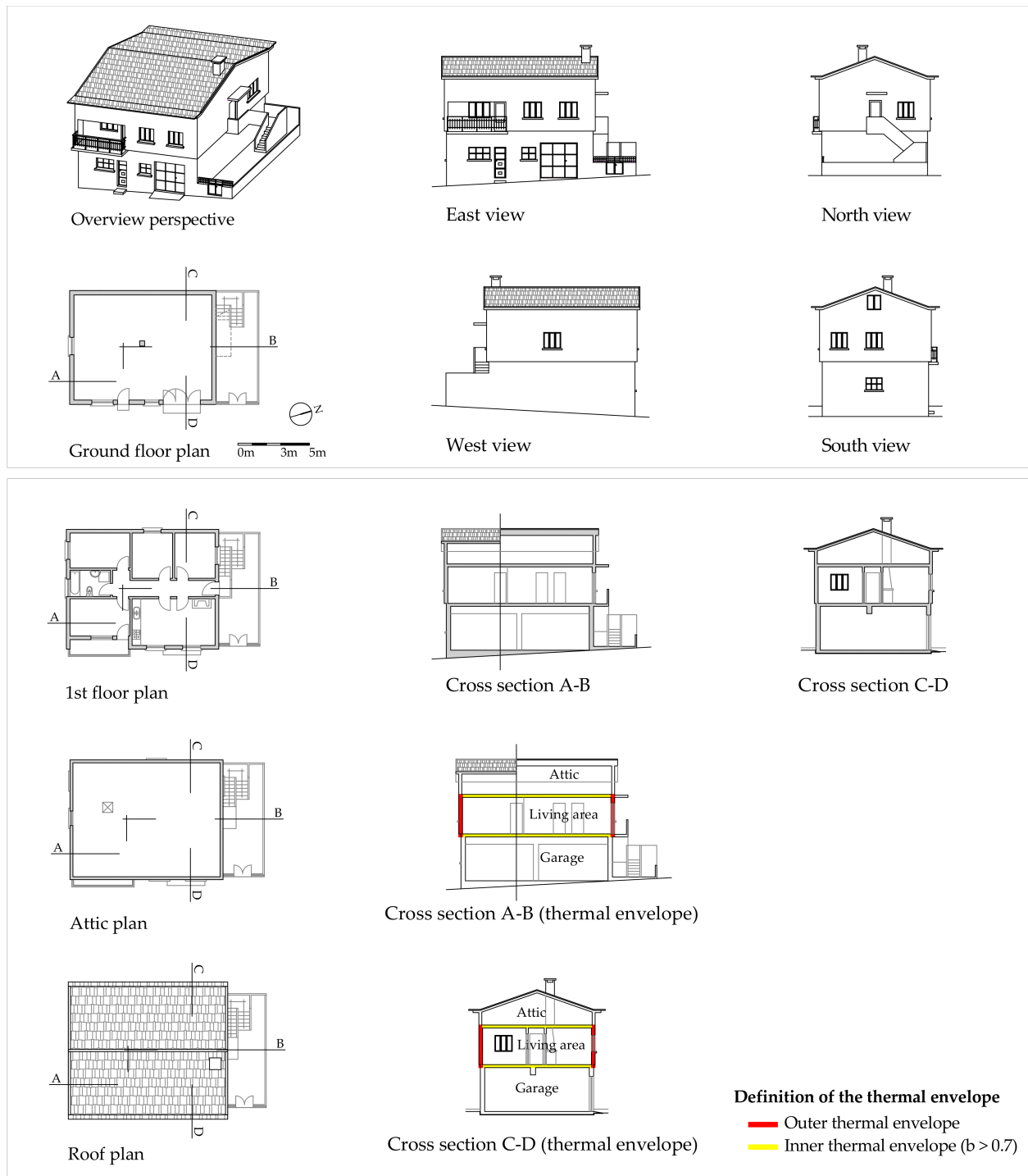


Figure 4. Case Study 2.

The building has a roof attic (hereafter identified as Attic 2), accessible for inspection through a small trapdoor located in the bathroom, neither air conditioned or compartmentalized, being the sloping roof made of ceramic tile resting on discontinuous wooden slats, providing a strong air intake. The exterior walls are made of double masonry of 15 and 11 cm thick hollow clay brick, with a 3 cm air gap, and plastered with 2.5 and 2.0 cm thick traditional mortar in the exterior and interior faces, respectively. The two slabs of the house are lightened, with prefabricated pre-stressed concrete beams and ceramic vaults, a total of 19 cm thick. The glazed openings are made of wooden frames and simple glass, with exterior protection of light-coloured metal sheet shutters. The building is highly insufficient in terms of thermal insulation, and the climate control in the heating season is carried out through a wood-burning fireplace (bio-mass) placed in the kitchen and operating practically continuously throughout the winter. The ventilation of heated spaces takes place naturally through the façade openings.

Figures 5 and 6 show the constructive details of the unheated spaces of Attic 2 and Garage 1, respectively. Tables 14 and 15 present the geometric characteristics and physical properties of the constructive elements of Attic 2 and Garage 1, respectively, which are necessary to quantify the value of b by the simplified calculation methods. Heat transfer via the ground was calculated based on EN ISO 13370 [31]. The ventilation of heated spaces takes place naturally through the façade openings. Attic 2 is considered strongly ventilated due to the numerous openings between the tiles and absence of a continuous coating. Garage 1 is considered poorly ventilated, being the only air intake made by slits in the base of the front door of the garage.

To obtain the temperature profiles, six battery-powered data loggers equipped with a temperature probe (Easylog EL-GFX-2) were used. Two data loggers were placed on the second floor of the housing (INT), with two in Garage 1 (UnSp), one in Attic 2 (UnSp), and one outside (EXT), protected from direct solar radiation. All equipment was programmed to record the temperature at 15-minute intervals in a synchronized way. Measurements started on 10th April and ended on 23th April.

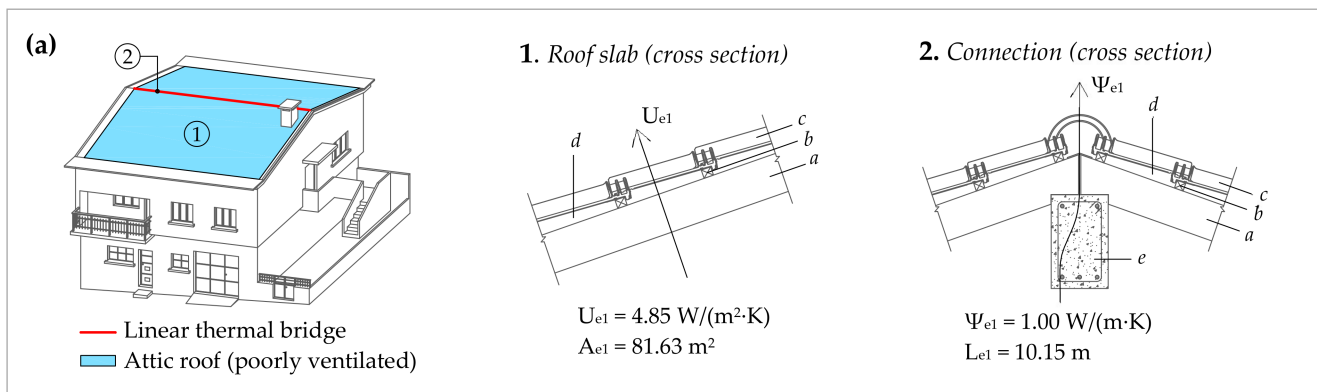


Figure 5. Cont.

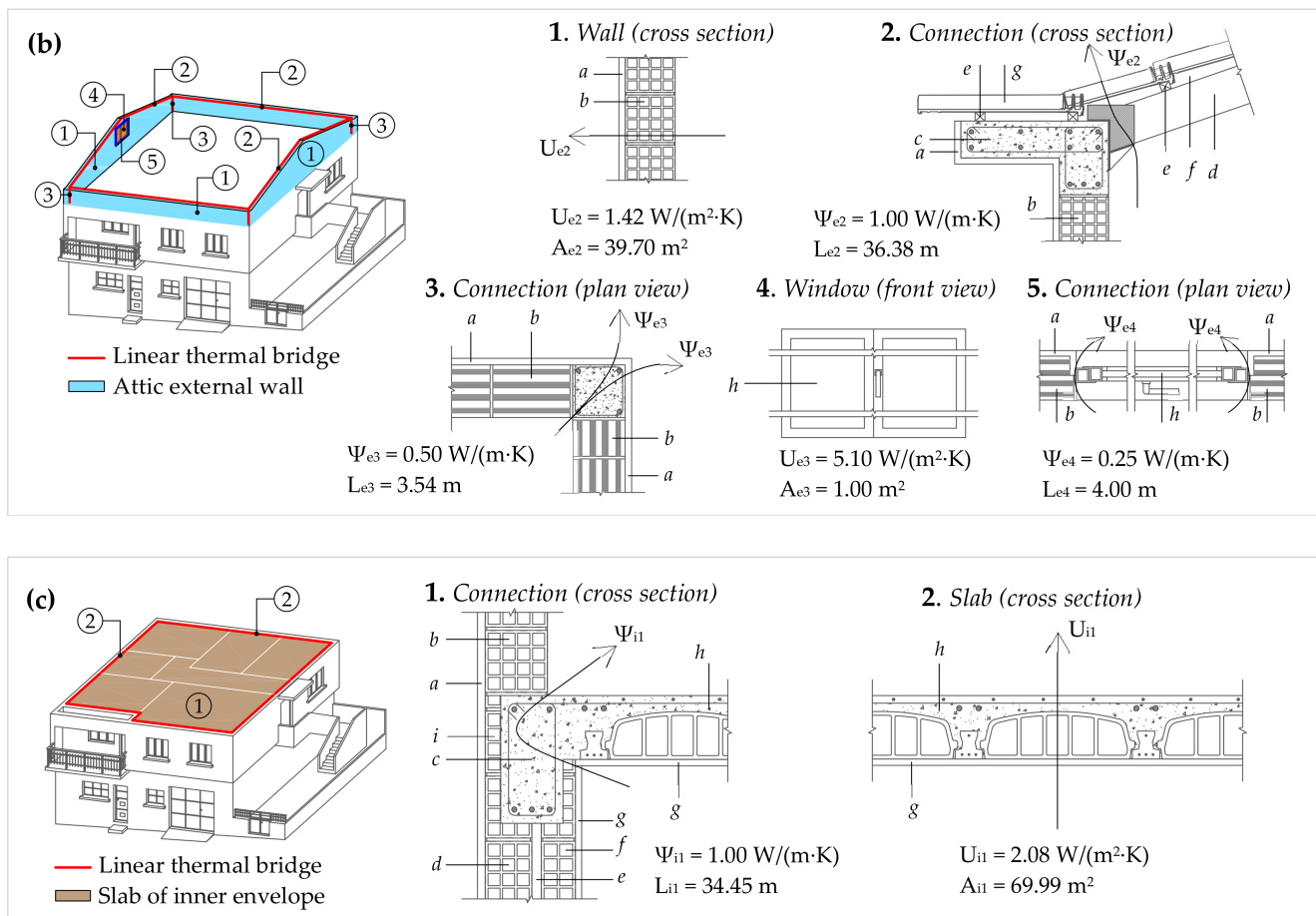


Figure 5. Characterization of the thermal envelope of Attic 2: (a) sloping roof slab separating the UnSp from the EXT: **Note 1:** No scale **Note 2:** (a) wooden beams ($8 \times 16 \text{ cm}^2$ cross section); (b) timber sleepers ($5 \times 7 \text{ cm}^2$ cross section); (c) ceramic roof tiles; (d) highly ventilated space, due to the lack of a continuous coating under the roof tile; (e) reinforced concrete beam. (b) walls and window separating the UnSp from the EXT: **Note 1:** No scale; **Note 2:** (a) traditional rendering mortar (2.5 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (b) hollow clay brick (20 cm) with $R = 0.52 \text{ m}^2\cdot\text{K}/\text{W}$; (c) reinforced concrete; (d) wooden beams ($8 \times 16 \text{ cm}^2$ cross section); (e) timber sleepers ($5 \times 7 \text{ cm}^2$ cross section); (f) space immediately below the ceramic tiles is considered strongly ventilated; (g) ceramic roof tile; (h) window of wooden frames, simple glass. (c) the horizontal slab that separates the INT from the UnSp: **Note 1:** No scale; **Note 2:** (a) traditional rendering mortar (2.5 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (b) hollow clay brick (20 cm) with $R = 0.52 \text{ m}^2\cdot\text{K}/\text{W}$; (c) reinforced concrete; (d) hollow clay brick (15 cm) with $R = 0.39 \text{ m}^2\cdot\text{K}/\text{W}$; (e) non-ventilated air gap (3 cm) with $R = 0.18 \text{ m}^2\cdot\text{K}/\text{W}$; (f) hollow clay brick (11 cm) with $R = 0.27 \text{ m}^2\cdot\text{K}/\text{W}$; (g) traditional rendering mortar (2.0 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (h) lightened slab with prefabricated pre-stressed concrete beams and ceramic vaults, a total of 19 cm thick ($R_{asc} = 0.27 \text{ m}^2\cdot\text{K}/\text{W}$); (i) hollow clay brick (4 cm) with $R = 0.10 \text{ m}^2\cdot\text{K}/\text{W}$.

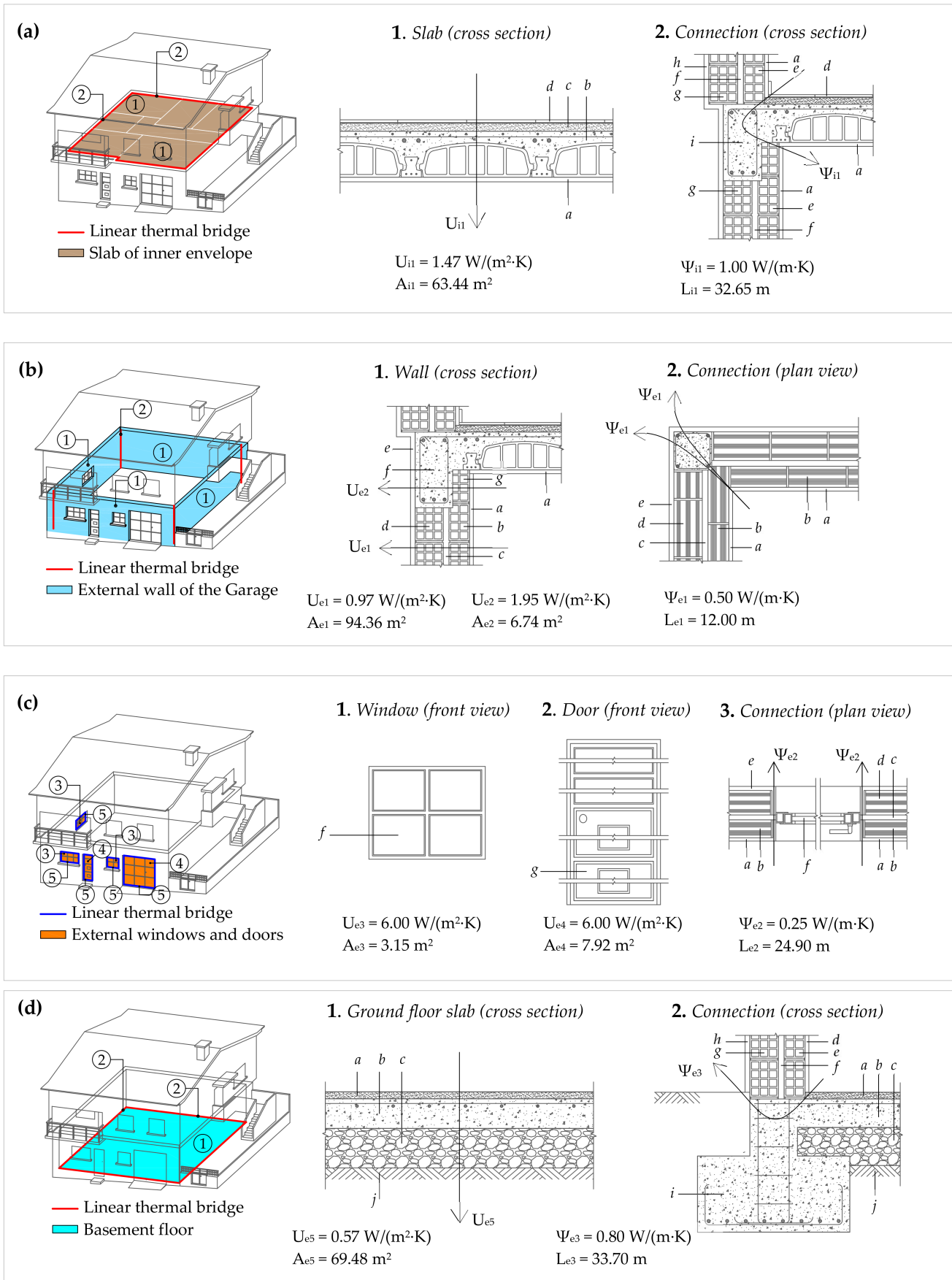


Figure 6. Characterization of the thermal envelope of Garage 1: (a) slab separating INT from UnSp:

Note 1: No scale; **Note 2:** (a) traditional rendering mortar (2.0 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (b) lightened slab with prefabricated pre-stressed concrete beams and ceramic vaults, a total of 19 cm thick ($R_{\text{desc}} = 0.30 \text{ m}^2\cdot\text{K}/\text{W}$); (c) levelling mortar (4 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (d) ceramic finishing (1 cm) with $\lambda = 1.3 \text{ W}/(\text{m}\cdot\text{K})$; (e) hollow clay brick (11 cm) with $R = 0.27 \text{ m}^2\cdot\text{K}/\text{W}$; (f) non-ventilated air gap (3 cm) with $R = 0.18 \text{ m}^2\cdot\text{K}/\text{W}$; (g) hollow clay brick (15 cm) with $R = 0.39 \text{ m}^2\cdot\text{K}/\text{W}$; (h) traditional rendering mortar (2.5 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (i) reinforced concrete 20 cm thick beam with $\lambda = 2.3 \text{ W}/(\text{m}\cdot\text{K})$. (b) walls separating the UnSp from the EXT: **Note 1:** No scale; **Note 2:** (a) traditional rendering mortar (2.0 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (b) hollow clay brick (11 cm) with $R = 0.27 \text{ m}^2\cdot\text{K}/\text{W}$; (c) non-ventilated air gap (3 cm) with $R = 0.18 \text{ m}^2\cdot\text{K}/\text{W}$; (d) hollow clay brick (15 cm) with $R = 0.39 \text{ m}^2\cdot\text{K}/\text{W}$; (e) traditional rendering mortar (2.5 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (f) reinforced concrete 20 cm thick beam with $\lambda = 2.3 \text{ W}/(\text{m}\cdot\text{K})$; (g) hollow clay brick (9 cm) with $R = 0.23 \text{ m}^2\cdot\text{K}/\text{W}$. (c) windows and doors separating the UnSp from the EXT: **Note 1:** No scale; **Note 2:** (a) traditional rendering mortar (2.0 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (b) hollow clay brick (11 cm) with $R = 0.27 \text{ m}^2\cdot\text{K}/\text{W}$; (c) non-ventilated air gap (3 cm) with $R = 0.18 \text{ m}^2\cdot\text{K}/\text{W}$; (d) hollow clay brick (15 cm) with $R = 0.39 \text{ m}^2\cdot\text{K}/\text{W}$; (e) traditional rendering mortar (2.5 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (f) garage window, with metal frame and simple glass; (g) garage door with metal frame, steel plate lining and partially glazed with simple glass. (d) the ground floor of UnSp: **Note 1:** No scale; **Note 2:** (a) levelling mortar (3.5 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (b) reinforced concrete (20 cm) with $\lambda = 2.3 \text{ W}/(\text{m}\cdot\text{K})$; (c) aggregate rockfill; (d) traditional rendering mortar (2.0 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (e) hollow clay brick (11 cm) with $R = 0.27 \text{ m}^2\cdot\text{K}/\text{W}$; (f) non-ventilated air gap (3 cm) with $R = 0.18 \text{ m}^2\cdot\text{K}/\text{W}$; (g) hollow clay brick (15 cm) with $R = 0.39 \text{ m}^2\cdot\text{K}/\text{W}$; (h) traditional rendering mortar (2.5 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (i) reinforced concrete foundation; (j) soil.

Table 14. Geometric and physical characteristics of Attic 2.

Volume	Vent	Elements that Separate INT from UnSp											
V_u m^3	n_e h^{-1}	U_{i1} $\text{W}/(\text{m}^2\cdot\text{K})$	A_{i1} m^2	Ψ_{i1} $\text{W}/(\text{m}\cdot\text{K})$	L_{i1} m								
118.97	10.0	2.08	69.99	1.00	34.45								
Elements that separate UnSp from EXT													
U_{e1} $\text{W}/(\text{m}^2\cdot\text{K})$	A_{e1} m^2	Ψ_{e1} $\text{W}/(\text{m}\cdot\text{K})$	L_{e1} m	U_{e2} $\text{W}/(\text{m}^2\cdot\text{K})$	A_{e2} m^2	Ψ_{e2} $\text{W}/(\text{m}\cdot\text{K})$	L_{e2} m	U_{e3} $\text{W}/(\text{m}^2\cdot\text{K})$	A_{e3} m^2	Ψ_{e3} $\text{W}/(\text{m}\cdot\text{K})$	L_{e3} m	Ψ_{e4} $\text{W}/(\text{m}\cdot\text{K})$	L_{e4} m
4.85	81.63	1.00	10.15	1.42	39.70	1.00	36.38	5.10	1.00	0.50	3.54	0.25	4.00

Table 15. Geometric and physical characteristics of Garage 1.

Volume	Vent	Elements that Separate INT from UnSp											
V_u m^3	n_e h^{-1}	U_{i1} $\text{W}/(\text{m}^2\cdot\text{K})$	A_{i1} m^2	Ψ_{i1} $\text{W}/(\text{m}\cdot\text{K})$	L_{i1} m								
208.44	0.50	1.47	63.44	1.00	32.65								
Elements that separate UnSp from EXT													
U_{e1} $\text{W}/(\text{m}^2\cdot\text{K})$	A_{e1} m^2	Ψ_{e1} $\text{W}/(\text{m}\cdot\text{K})$	L_{e1} m	U_{e2} $\text{W}/(\text{m}^2\cdot\text{K})$	A_{e2} m^2	Ψ_{e2} $\text{W}/(\text{m}\cdot\text{K})$	L_{e2} m	U_{e3} $\text{W}/(\text{m}^2\cdot\text{K})$	A_{e3} m^2	U_{e4} $\text{W}/(\text{m}^2\cdot\text{K})$	A_{e4} m^2		
0.97	94.36	0.50	12.00	1.95	6.74	0.25	24.90	6.00	3.15	6.00	7.92		

3.3. Case Study 3

Case study 3 comprises of a two-storey single-family house (Figure 7), built in 2020, when the REH [13] was in force in Portugal. The building is in the municipality of Covilhã, at an altitude of 533 m, on a site with a predominance of altered granite massifs and granite

residual soil. The ground floor includes a garage, living room, kitchen, pantry, a bedroom and a toilet. The second floor includes two bedrooms, an office and two toilets.



Figure 7. Case Study 3.

The building has a concrete flat roof with 20 cm thick and 12 cm of XPS on the outer face. The exterior walls consist of double masonry with a 14 cm air gap, partially filled with 10 cm of XPS. The ground floor is built over a ventilated sanitary void to prevent the effect of radon gas and consists of a lightened slab with 10 cm thick of XPS. The glazed openings are made of aluminium frames with thermal cutting and double glazing, with exterior protection with dark coloured shutters. The climate control in the heating season is carried out through a biomass boiler with storage tank and radiators distributed throughout the house. Ventilation of heated spaces takes place naturally through the façade openings. The garage (hereafter identified as Garage 2) is considered poorly ventilated, being the only air intake made by slits in the base of the front door of the garage.

Figure 8 shows the envelope constructive details of Garage 2, while Table 16 presents the geometric characteristics and physical properties of such elements, necessary to quantify the value of b by the simplified calculation methods.

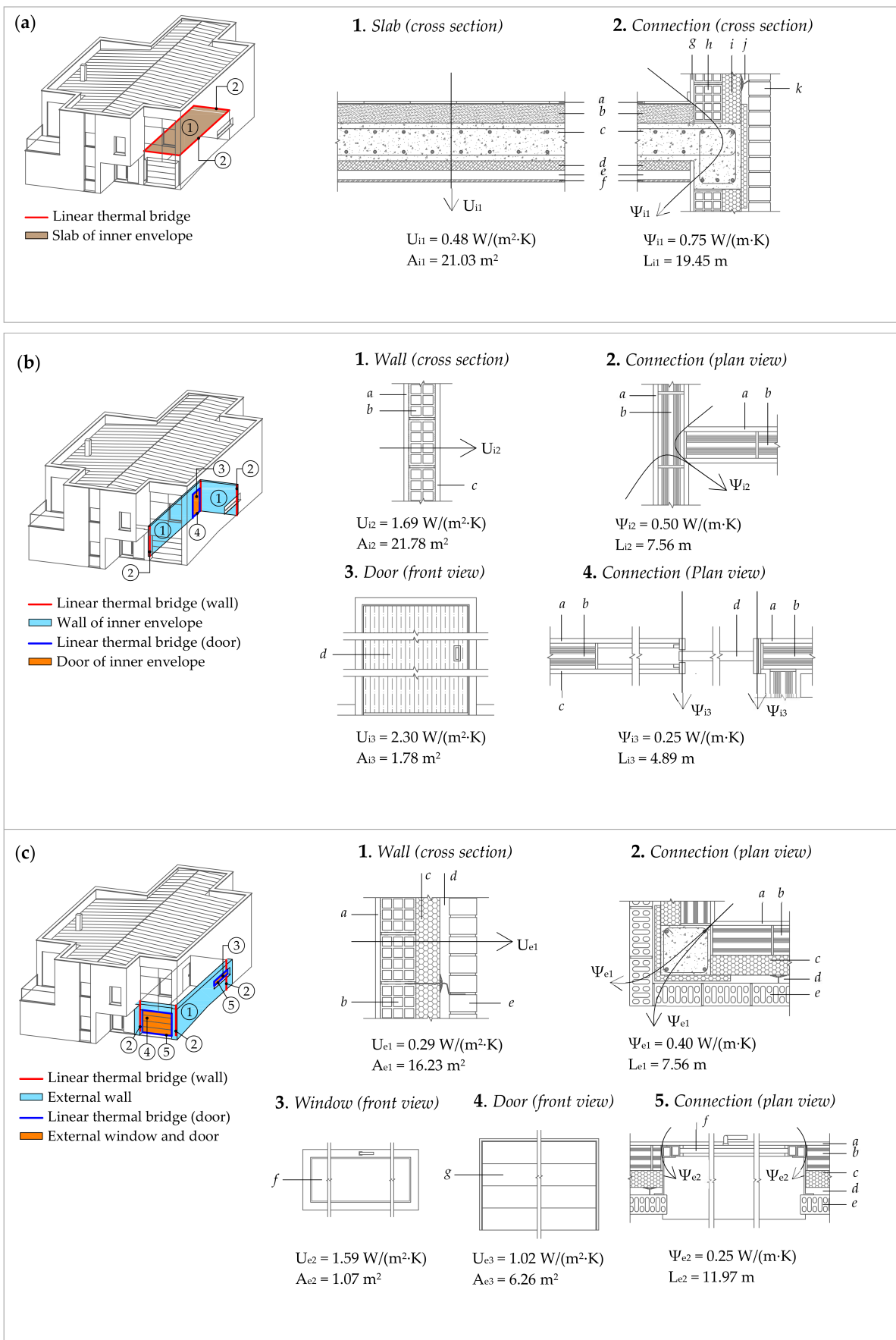


Figure 8. Cont.

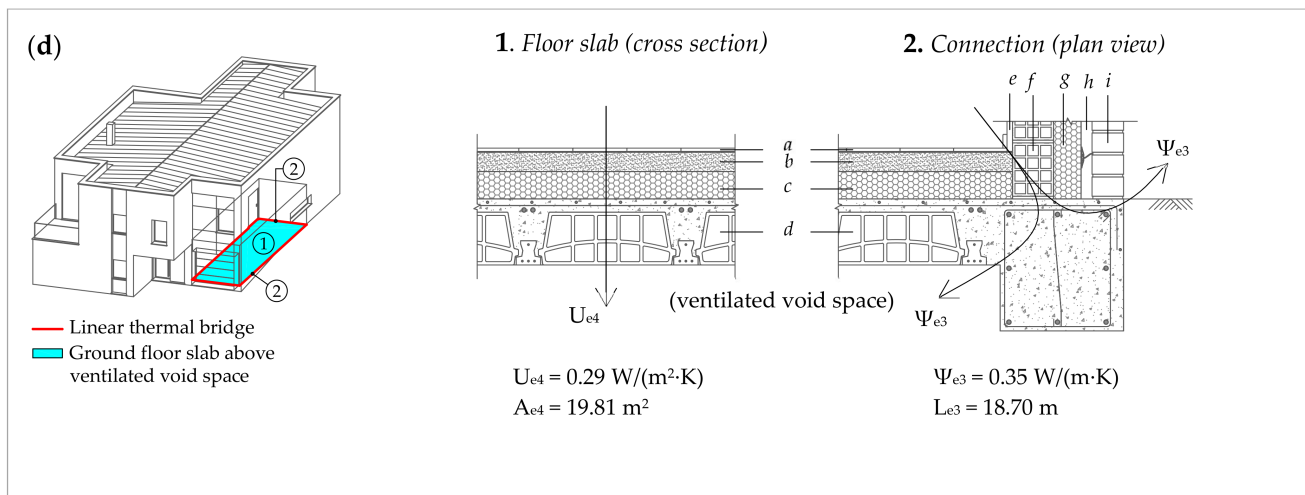


Figure 8. Characterization of the thermal envelope of Garage 2: (a) the horizontal slab of the upper floor that separates the interior (INT) from Garage 2 (UnSp): **Note 1:** No scale; **Note 2:** (a) wood finishing (1.3 cm) with $\lambda = 0.17 \text{ W}/(\text{m}\cdot\text{K})$; (b) lightweight concrete (10 cm) with $\lambda = 0.7 \text{ W}/(\text{m}\cdot\text{K})$; (c) reinforced concrete slab (20 cm) with $\lambda = 2.3 \text{ W}/(\text{m}\cdot\text{K})$; (d) mineral wool (5 cm) with $\lambda = 0.042 \text{ W}/(\text{m}\cdot\text{K})$; (e) non-ventilated air gap (5 cm) with $R_{\text{desc}} = 0.21 \text{ m}^2\cdot\text{K}/\text{W}$; (f) plasterboard (1.3 cm) with $\lambda = 0.25 \text{ W}/(\text{m}\cdot\text{K})$; (g) traditional plaster coating (2 cm) with $\lambda = 0.40 \text{ W}/(\text{m}\cdot\text{K})$; (h) hollow clay brick (15 cm) with $R = 0.39 \text{ m}^2\cdot\text{K}/\text{W}$; (i) extruded polystyrene (10 cm) with $\lambda = 0.037 \text{ W}/(\text{m}\cdot\text{K})$; (j) non-ventilated air gap (4 cm) with $R = 0.18 \text{ m}^2\cdot\text{K}/\text{W}$; (k) perforated ceramic brick (11 cm) with $R = 0.30 \text{ m}^2\cdot\text{K}/\text{W}$. (b) the walls and door of the ground floor that separate the interior (INT) from Garage 2 (UnSp): **Note 1:** No scale; **Note 2:** (a) traditional plaster coating (2 cm) with $\lambda = 0.40 \text{ W}/(\text{m}\cdot\text{K})$; (b) hollow clay brick (11 cm) with $R = 0.27 \text{ m}^2\cdot\text{K}/\text{W}$; (c) traditional rendering mortar (2.0 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (d) sliding woden door (4 cm) with $\lambda = 0.23 \text{ W}/(\text{m}\cdot\text{K})$. (c) the walls, window, and door that separate Garage 2 (UnSp) from the exterior environment (EXT): **Note 1:** No scale; **Note 2:** (a) traditional rendering mortar (2 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (b) hollow clay brick (15 cm) with $R = 0.39 \text{ m}^2\cdot\text{K}/\text{W}$; (c) extruded polystyrene (10 cm) with $\lambda = 0.037 \text{ W}/(\text{m}\cdot\text{K})$; (d) non-ventilated air gap (4 cm) with $R = 0.18 \text{ m}^2\cdot\text{K}/\text{W}$; (e) perforated ceramic brick (11 cm) with $R = 0.30 \text{ m}^2\cdot\text{K}/\text{W}$; (f) window; (g) garage front door. (d) the floor slab separating Garage 2 (UnSp) from a ventilated void under the garage floor: **Note 1:** No scale; **Note 2:** (a) traditional ceramic finishing (1 cm) with $\lambda = 1.3 \text{ W}/(\text{m}\cdot\text{K})$; (b) lightweight concrete (7 cm) with $\lambda = 0.7 \text{ W}/(\text{m}\cdot\text{K})$; (c) extruded polystyrene (10 cm) with $\lambda = 0.037 \text{ W}/(\text{m}\cdot\text{K})$; (d) lightened slab with prefabricated pre-stressed concrete beams and ceramic vaults with a total of 24 cm thick ($R_{\text{desc}} = 0.30 \text{ m}^2\cdot\text{K}/\text{W}$); (e) traditional rendering mortar (2 cm) with $\lambda = 1.8 \text{ W}/(\text{m}\cdot\text{K})$; (f) hollow clay brick (15 cm) with $R = 0.39 \text{ m}^2\cdot\text{K}/\text{W}$; (g) extruded polystyrene (10 cm) with $\lambda = 0.037 \text{ W}/(\text{m}\cdot\text{K})$; (h) non-ventilated air gap (4 cm) with $R = 0.18 \text{ m}^2\cdot\text{K}/\text{W}$; (i) perforated ceramic brick (11 cm) with $R = 0.30 \text{ m}^2\cdot\text{K}/\text{W}$.

Table 16. Geometric and physical characteristics of Garage 2.

Volume Vent		Elements that Separate INT from UnSp											
V_u m^3	n_e h^{-1}	U_{i1} $\text{W}/(\text{m}^2\cdot\text{K})$	A_{i1} m^2	Ψ_{i1} $\text{W}/(\text{m}\cdot\text{K})$	L_{i1} m	U_{i2} $\text{W}/(\text{m}^2\cdot\text{K})$	A_{i2} m^2	Ψ_{i2} $\text{W}/(\text{m}\cdot\text{K})$	L_{i2} m	U_{i3} $\text{W}/(\text{m}^2\cdot\text{K})$	A_{i3} m^2	Ψ_{i3} $\text{W}/(\text{m}\cdot\text{K})$	L_{i3} m
49.92	0.50	0.48	21.03	0.75	19.45	1.69	21.78	0.50	7.56	2.30	1.78	0.25	4.89
Elements that separate UnSp from EXT													
U_{e1} $\text{W}/(\text{m}^2\cdot\text{K})$	A_{e1} m^2	Ψ_{e1} $\text{W}/(\text{m}\cdot\text{K})$	L_{e1} m	U_{e2} $\text{W}/(\text{m}^2\cdot\text{K})$	A_{e2} m^2	Ψ_{e2} $\text{W}/(\text{m}\cdot\text{K})$	L_{e2} m	U_{e3} $\text{W}/(\text{m}^2\cdot\text{K})$	A_{e3} m^2				
0.29	16.23	0.40	7.56	1.59	1.07	0.25	11.97	1.02	6.26				

To obtain the temperature profiles, sixteen battery-powered data loggers equipped with a temperature probe (Easylog EL-GFX-2), were used. Nine data loggers were placed in the housing heated area (INT): four in the living room, three in the pantry and two in the office above the garage (2nd floor). Three data loggers were placed in Garage 2 (UnSp), with four outside (EXT), protected from direct solar radiation. All equipment was programmed to record the temperature at 15-min intervals in a synchronized way. Measurements started on 7 November and ended on 4 December.

4. Results

This section presents the value of the measured on-site adjustment factor, which is evaluated based on the temperature records. The values of the adjustment factor estimated based on the simplified methods are also presented. The comparison of the obtained results allowed us to evaluate the influence of the simplifications adopted in the estimation of the adjustment factor (b).

4.1. Case Study 1

4.1.1. Measured Values

The daily temperature profiles for Attic 1 are shown in Figure 9. The (INT) temperature peaks recorded in the house were due to the intermittent use of the air conditioning. Temperature in Attic 1 is affected by solar radiation, with some lag compared to the outside temperature (EXT), due to the effect of thermal inertia. In order to reduce the effect of the non-stationary outdoor temperature regime, the adjustment factor (b) was calculated by Equation (10), considering the average values of INT, EXT, and UnSp temperatures recorded during the entire measurement period (Figure 10). The mean value of b obtained for Attic 1 was 0.70.

Figure 11 shows the daily variation in the adjustment factor for Attic 1. It is observed that as the mean external temperature increases, the proportions between INT, UnSp and EXT temperatures also varied and b tends to decrease.

4.1.2. Simplified Methods

Table 17 shows the values of the estimated adjustment factor (b) for Attic 1, by using the reported methods, namely the EN ISO 13789 [8], BR 443 [10], TGD-L [11], RCCTE [12], REH/DEE [13,14], DB-HE [15], RE2020 [16] and UNI/TS [17]. For each method, the formulas and parameters used are described, as well as the source data.

4.2. Case Study 2

4.2.1. Measured Values

The daily temperature profiles for Attic 2 and Garage 1 are shown in Figure 12. The interior temperature (INT) is almost stable during the measurement period. The temperature in Attic 2 was strongly affected by the high ventilation provided by the characteristics of the sloped roof, which made the attic temperature closely follow the variation of the outside temperature (EXT). In order to reduce the effect of the non-stationary outdoor temperature regime, the adjustment factor (b) was calculated by Equation (10), considering the average values of INT, EXT and UnSp temperatures recorded during the entire measurement period, as shown in Figure 13. The value of b obtained on-site for Garage 1 was 0.24, while for Attic 2 it was 0.99.

Figure 14 shows the daily variation in the adjustment factor for Attic 2 and Garage 1. In this case the variation of the proportions between INT, UnSp and EXT temperatures is not so evident.

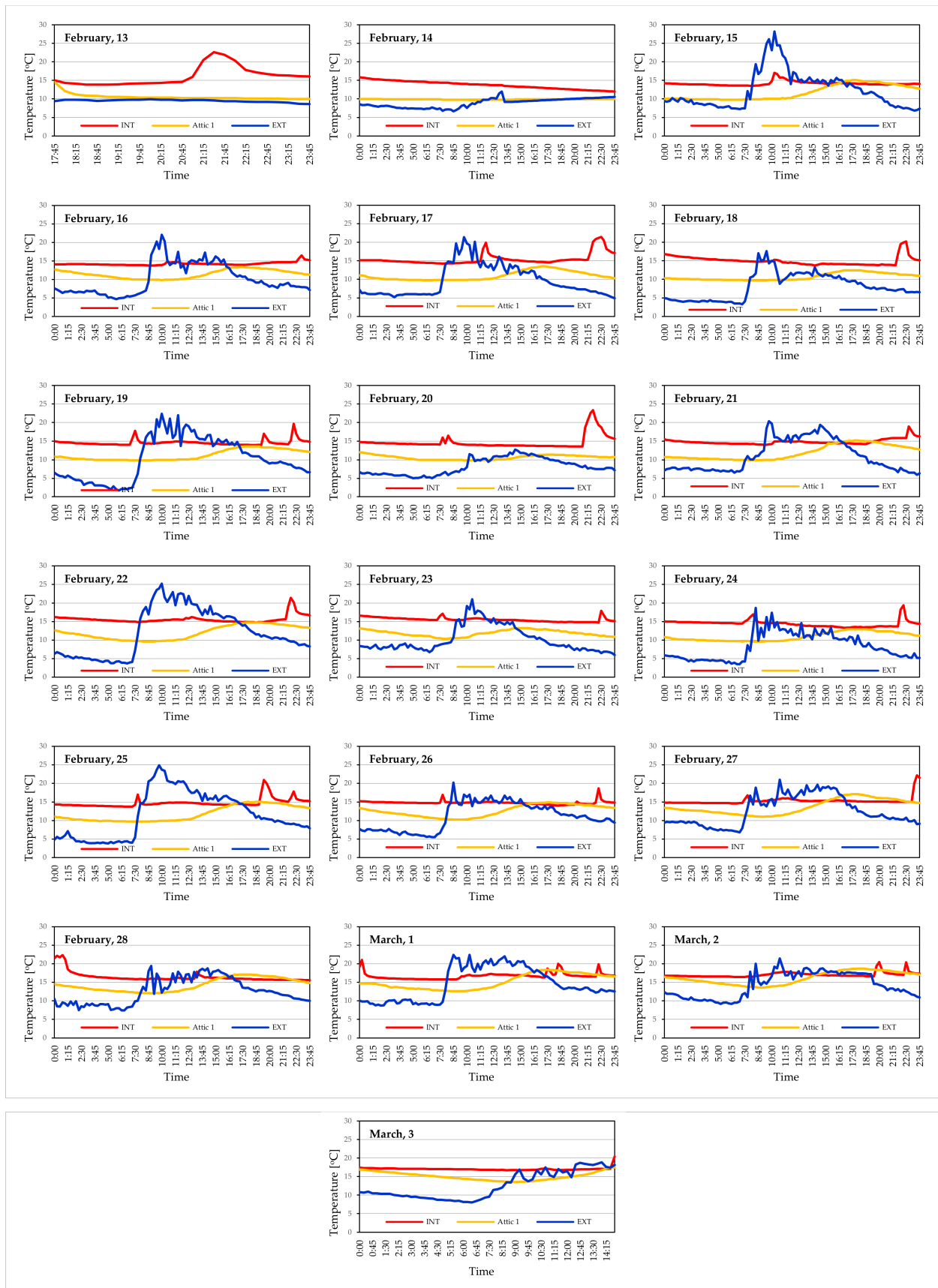


Figure 9. Daily temperature profile in Attic 1.

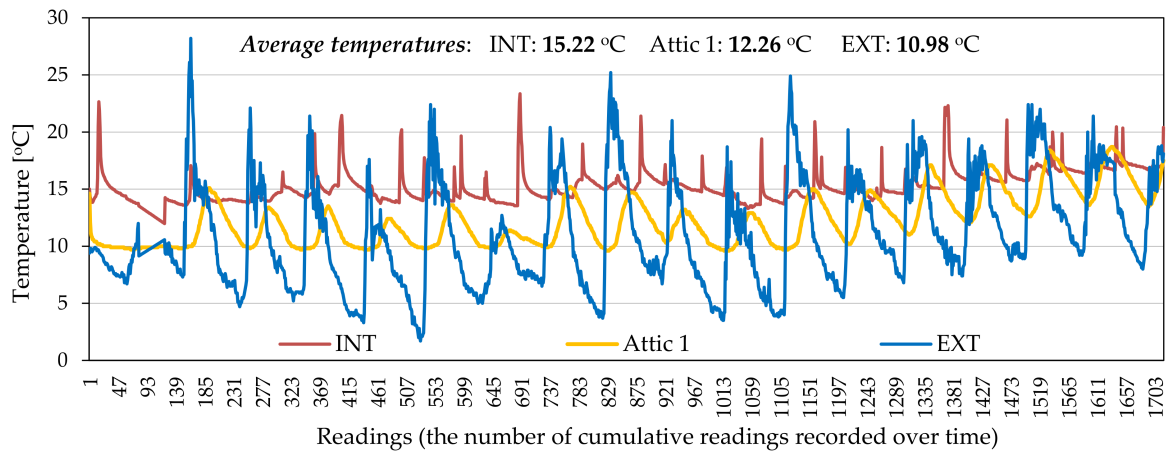


Figure 10. Global temperature profile in Attic 1.

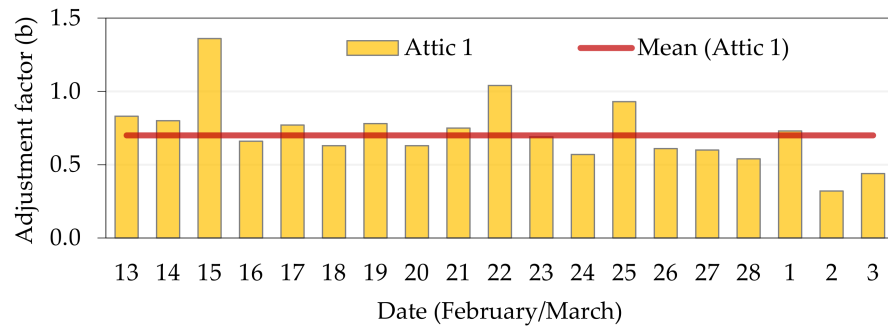


Figure 11. Daily variation of the adjustment factor (b) for Attic 1.

Table 17. Values of the estimated adjustment factor (b) for Attic 1.

Methodology	Formulas/Parameters	Source Data	b*
ISO 13789	$H_{iu} = \sum(U_i \times A_i) + \sum(\Psi_i \times L_i) = 96.3 + 45.7 = 142.0 \text{ W/K}$	Table 13	0.40
	$H_{ue} = \sum(U_e \times A_e) + \sum(\Psi_e \times L_e) + 0.33 \times n_e \times V_u = 48.9 + 34.3 + 0.33 \times 0.5 \times 79.32 = 96.3 \text{ W/K}$		
BR 443	$H_{iu} = \sum(U_i \times A_i) = 96.3 \text{ W/K}$	Table 13	0.39
	$H_{ue} = \sum(U_e \times A_e) + 0.33 \times n_e \times V_u = 48.9 + 0.33 \times 0.5 \times 79.32 = 62.0 \text{ W/K}$		
TGD-L	Tables 3–5: Typical R_u values of UnSp Equation (25) ($U_o = 0.75 \text{ W}/(\text{m}^2 \cdot \text{K})$; $R_u = 0.09 \text{ m}^2 \cdot \text{K}/\text{W}$)	Table 13	0.94
RCCTE	Table 6: Unventilated attic (open area of $320 \text{ cm}^2/128.4 \text{ m}^2$ or $249 \text{ mm}^2/\text{m}^2$) $A_i = 128.4 \text{ m}^2$; $A_e = 148.3 \text{ m}^2$; $A_i/A_e = 0.87$	Table 13	0.80
REH/DEE	Table 7: All components well-sealed, small ventilation openings (f) $V_u = 79.32 \text{ m}^3$; $A_i/A_e = 0.87$	Table 13	0.80
DB-HE	Tables 8 and 9: All components well-sealed, small ventilation openings (Case 1) $A_i/A_e = 0.87$; INT to UnSp (insulated) and UnSp to EXT (insulated **)	Table 13	0.94
	Table 10d: $A_i/A_e = 0.87$; INT to UnSp (insulated) and UnSp to EXT (insulated)		
RE2020	Table 11: Small ventilation openings: $A_o/A_c = 0.0320 \text{ m}^2/128.4 \text{ m}^2 = 0.00025 \text{ m}^2/\text{m}^2$ ($U_{v,ue} = 0.3$)	Table 13	0.65
UNI/TS	Table 12: Attic with insulated roof	Table 13	0.70

* For the ISO 13789 and BR 443, $b = H_{ue}/(H_{ue} + H_{iu})$. In the presented formulas, H_{iu} and H_{ue} are expressed in W/K. ** In DB-HE, there is no option for both insulated partitions, UnSp to EXT and INT to UnSp. The partition UnSp to EXT was assumed not insulated for calculations.

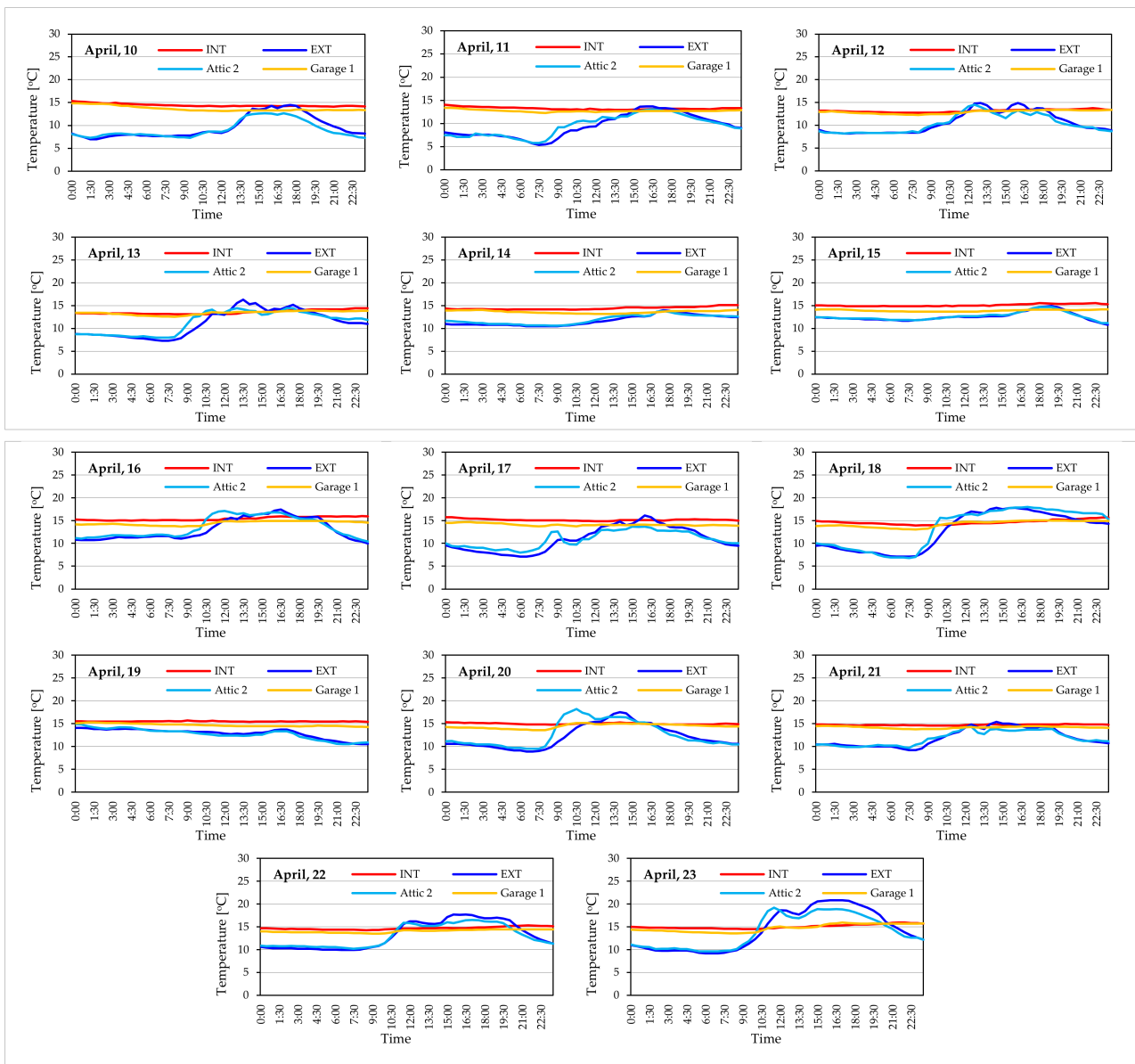


Figure 12. Daily temperature profile in Attic 2 and Garage 1.

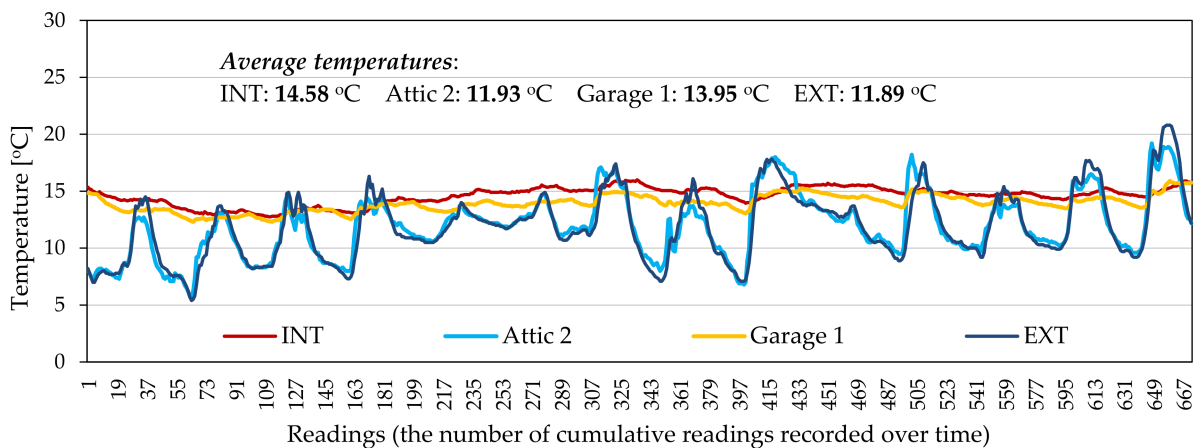


Figure 13. Global temperature profile in Attic 2 and Garage 1.

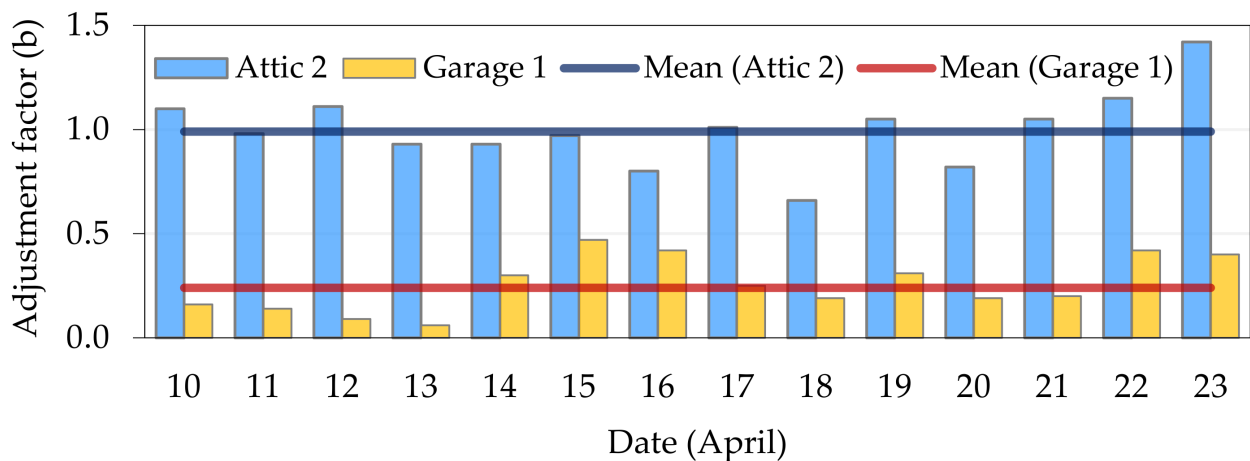


Figure 14. Daily variation of the adjustment factor (b) for Attic 2 and Garage 1.

4.2.2. Simplified Methods

Tables 18 and 19 show the values of the estimated adjustment factor (b) for Attic 2 and Garage 1, respectively, by using the reported methods, namely the EN ISO 13789 [8], BR 443 [10], TGD-L [11], RCCTE [12], REH/DEE [13,14], DB-HE [15], RE2020 [16] and UNI/TS [17]. For each method, the formulas and parameters used are described, as well as the source data.

Table 18. Values of the estimated adjustment factor (b) for Attic 2.

Methodology	Formulas/Parameters	Source Data	b *
ISO 13789	$H_{iu} = \sum(U_i \times A_i) + \sum(\Psi_i \times L_i) = 145.58 + 34.45 = 180.0 \text{ W/K}$	Table 14	0.83
	$H_{ue} = \sum(U_e \times A_e) + \sum(\Psi_e \times L_e) + 0.33 \times n_e \times V_u = 457.38 + 49.3 + 0.33 \times 10 \times 118.97 = 899.3 \text{ W/K}$		
BR 443	$H_{iu} = \sum(U_i \times A_i) = 145.6 \text{ W/K}$	Table 14	0.85
	$H_{ue} = \sum(U_e \times A_e) + 0.33 \times n_e \times V_u = 457.38 + 0.33 \times 10 \times 118.97 = 850.0 \text{ W/K}$		
TGD-L	Tables 3–5: $R_u = 0.09 \text{ m}^2 \cdot \text{K/W}$; $U_o = 2.08 \text{ W/(m}^2 \cdot \text{K)}$ Equation (25)	Table 14	0.84
RCCTE	Table 6: Strongly ventilated attic $A_i = 69.99 \text{ m}^2$; $A_e = 122.33 \text{ m}^2$; $A_i/A_e = 0.57$	Table 14	1.00
REH/DEE	Table 7: Large or numerous permanent ventilation openings (F) $V_u = 118.97 \text{ m}^3$; $A_i/A_e = 0.57$	Table 14	1.00
DB-HE	Tables 8 and 9: Large or numerous permanent ventilation openings (Case 2) $A_i/A_e = 0.57$; INT to UnSp (not insulated) and UnSp to EXT (not insulated)	Table 14	0.87
RE2020	Table 10b: $A_i/A_e = 0.57$; INT to UnSp (not insulated) and UnSp to EXT (not insulated) Table 11: Strongly ventilated attic ($U_{v,ue} = 9$)	Table 14	0.85
UNI/TS	Table 12: Attic with high ventilation rate without felt or board cladding	Table 14	1.00

* For the ISO 13789 and BR 443, $b = H_{ue}/(H_{ue} + H_{iu})$. In the presented formulas, H_{iu} and H_{ue} are expressed in W/K.

Table 19. Values of the estimated adjustment factor (b) for Garage 1.

Methodology	Formulas/Parameters	Source Data	b *
ISO 13789	$H_{iu} = \sum(U_i \times A_i) + \sum(\Psi_i \times L_i) = 93.26 + 32.65 = 125.9 \text{ W/K}$	Table 15	0.63
	$H_{ue} = \sum(U_e \times A_e) + \sum(\Psi_e \times L_e) + 0.33 \times n_e \times V_u = 171.09 + 12.23 + 0.33 \times 0.50 \times 208.44 = 217.7 \text{ W/K}$		
BR 443	$H_{iu} = \sum(U_i \times A_i) = 93.3 \text{ W/K}$	Table 15	0.69
	$H_{ue} = \sum(U_e \times A_e) + 0.33 \times n_e \times V_u = 171.09 + 0.33 \times 0.50 \times 208.44 = 205.5 \text{ W/K}$		
TGD-L	Tables 3–5: $R_u = 0.25 \text{ m}^2 \cdot \text{K/W}$; $U_o = 1.47 \text{ W}/(\text{m}^2 \cdot \text{K})$ Equation (25)	Table 15	0.73
RCCTE	Table 6: Private garage $A_i = 63.44 \text{ m}^2$; $A_e = 112.17 \text{ m}^2$; $A_i/A_e = 0.57$	Table 15	0.80
REH/DEE	Table 7: All components sealed, without ventilation openings (f) $V_u = 208.44 \text{ m}^3$; $A_i/A_e = 0.57$	Table 15	0.90
DB-HE	Tables 8 and 9: All components sealed, without ventilation openings (Case 1) $A_i/A_e = 0.57$; INT to UnSp (not insulated) and UnSp to EXT (not insulated)	Table 15	0.77
RE2020	Table 10b: $A_i/A_e = 0.57$; INT to UnSp (not insulated) and UnSp to EXT (not insulated) Table 11: Garage ($U_{v,ue} = 3$)	Table 15	0.75
UNI/TS	Table 12: Unheated Space with external doors and windows and at least two external walls	Table 15	0.60

* For the ISO 13789 and BR 443, $b = H_{ue}/(H_{ue} + H_{iu})$. In the presented formulas, H_{iu} and H_{ue} are expressed in W/K.

4.3. Case Study 3

4.3.1. Measured Values

Due to the high number of measurements in Case Study 3, only some of the typical daily records for Garage 2 are illustrated in Figure 15, namely the records between 20 November and 4 December. The interior temperature (INT) was almost stable during the measurement period due to continuous heating. As expected, the temperatures in Garage 2 closely followed the INT temperature variation, since the garage is strongly insulated in the external envelope and poorly ventilated. In order to reduce the effect of the non-stationary outdoor temperature regime, the adjustment factor (b) was calculated by Equation (10), considering the average values of INT, EXT and UnSp temperatures recorded during the entire measurement period, as shown in Figure 16. The value of b obtained for Garage 2 was 0.20. Figure 17 shows the daily variation in the adjustment factor (b) for Garage 2. It can be observed that the values of b remain relatively stable for the entire measurement period.

4.3.2. Simplified Methods

The values obtained for the Garage 2, by using the here analysed simplified methods, are presented in Table 20. For each method, the source data, formulae and parameters used are mentioned.

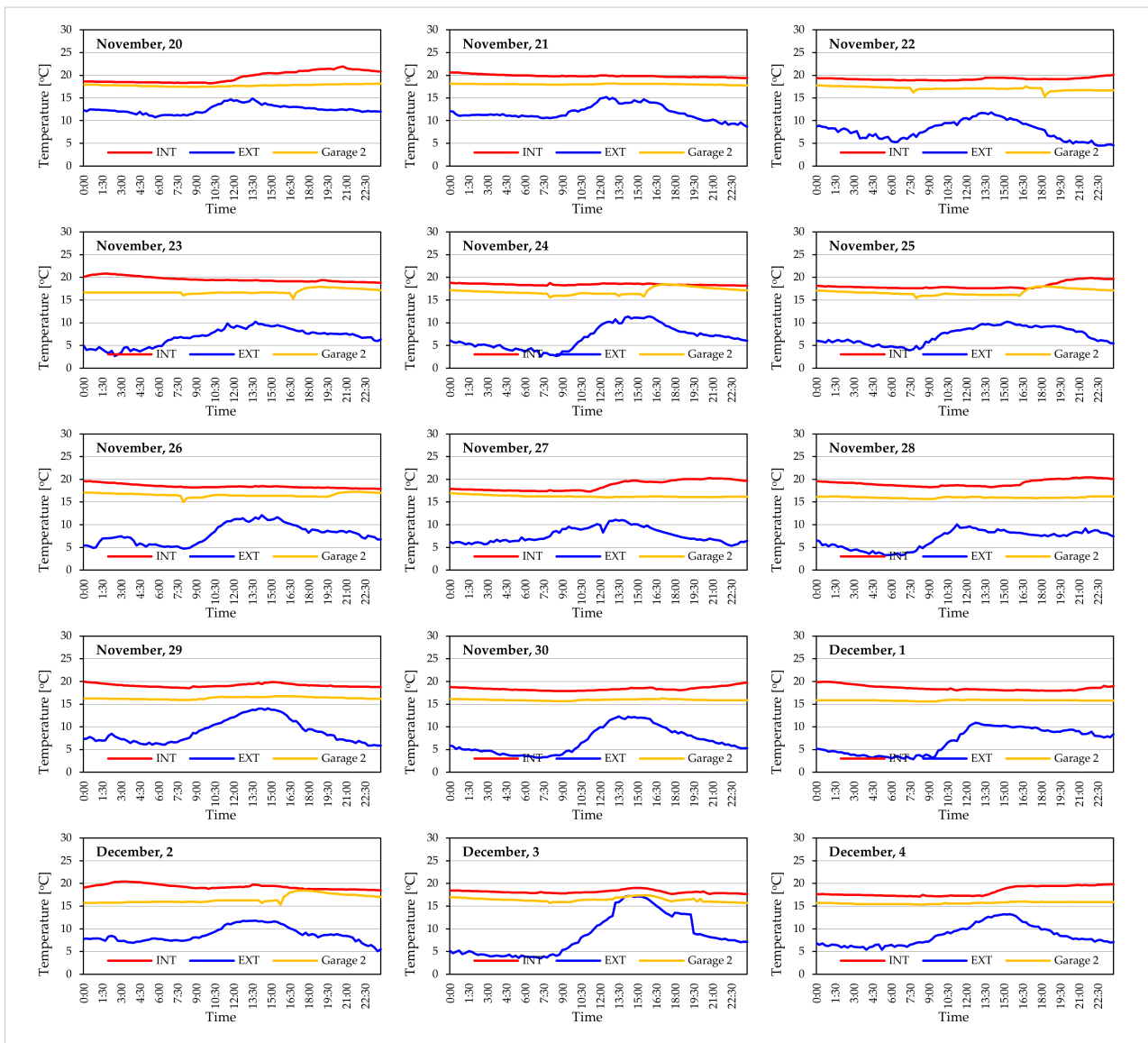


Figure 15. Daily temperature profile in the Garage 2.

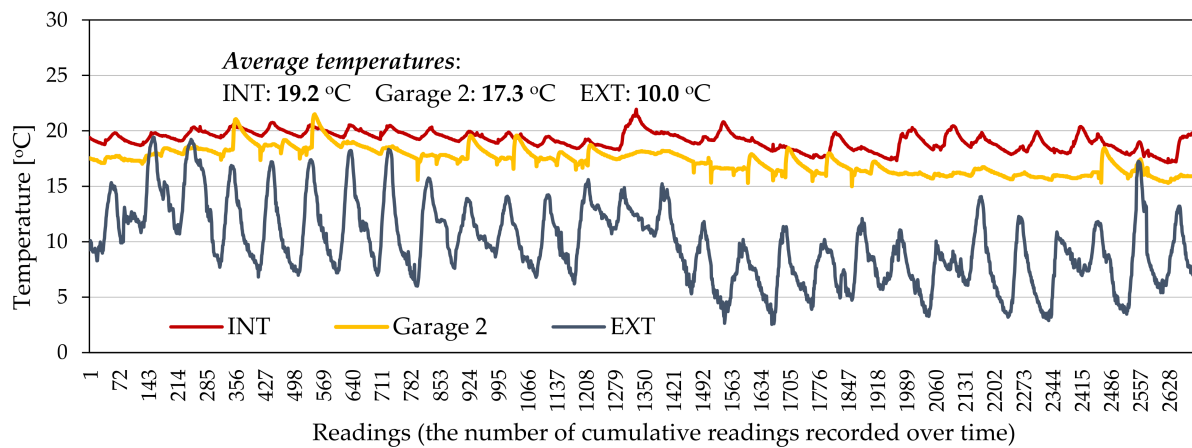


Figure 16. Global temperature profile in Garage 2.

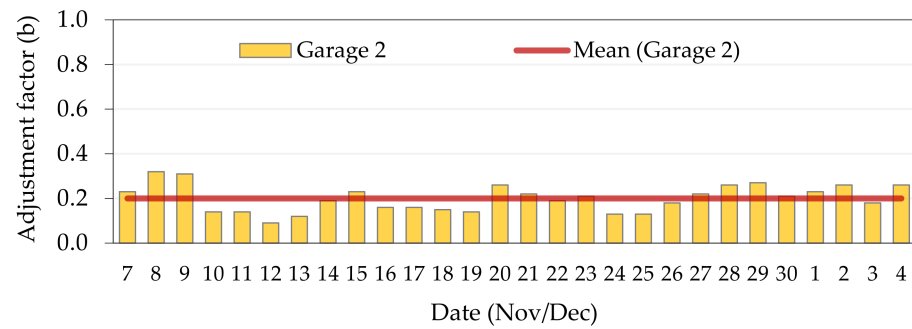


Figure 17. Daily variation of the adjustment factor (b) for Garage 2.

Table 20. Values of the estimated adjustment factor (b) for Garage 2.

Methodology	Formulas/Parameters	Source Data	b *
ISO 13789	$H_{iu} = \sum(U_i \times A_i) + \sum(\Psi_i \times L_i) = 51.00 + 19.59 = 70.59 \text{ W/K}$	Table 16	0.28
	$H_{ue} = \sum(U_e \times A_e) + \sum(\Psi_e \times L_e) + 0.33 \times n_e \times V_u = 12.79 + 6.02 + 0.33 \times 0.5 \times 49.92 = 27.0 \text{ W/K}$		
BR 443	$H_{iu} = \sum(U_i \times A_i) = 51.0 \text{ W/K}$	Table 16	0.29
	$H_{ue} = \sum(U_e \times A_e) + 0.33 \times n_e \times V_u = 12.79 + 0.33 \times 0.5 \times 49.92 = 21.0 \text{ W/K}$		
TGD-L	Tables 3–5: $R_u = 0.68 \text{ m}^2 \cdot \text{K/W}$; $U_o = \sum(U_i \times A_i) / \sum(A_i) = 1.14 \text{ W}/(\text{m}^2 \cdot \text{K})$ Equation (25)	Table 16	0.56
RCCTE	Table 6: Private garage	Table 16	0.50
	$A_i = 44.59 \text{ m}^2$; $A_e = 23.56 \text{ m}^2$; $A_i/A_e = 1.89$		
REH/DEE	Table 7: All components sealed, without ventilation openings (f)	Table 16	0.60
	$V_u = 49.92 \text{ m}^3$; $A_i/A_e = 1.89$		
DB-HE	Tables 8 and 9: All components sealed, without ventilation openings (Case 1)	Table 16	0.44
	$A_i/A_e = 1.89$; INT to UnSp (not insulated) and UnSp to EXT (insulated)		
RE2020	Table 10c: $A_i/A_e = 1.89$; INT to UnSp (not insulated) and UnSp to EXT (insulated)	Table 16	0.20
	Table 11: Garage ($U_{v,ue} = 3$)		
UNI/TS	Table 12: Unheated Space with external doors and windows and at least two external walls	Table 16	0.60

* For the ISO 13789 and BR 443, $b = H_{ue}/(H_{ue} + H_{iu})$. In the presented formulas, H_{iu} and H_{ue} are expressed in W/K.

5. Discussion

Figure 18 shows the results obtained for Case Study 1. It can be seen that the on-site measured value of the adjustment factor, b , is higher than those obtained by EN ISO 13789 and BR 443, which is mainly due to the uncertainty on defining the air change rate. The RE2020 and UNI/TS methods compare well with the measured value, while the TGD-L, RCCTE, REH/DEE and DB-HE methods clearly overestimated the b -value. The TGD-L, RCCTE and REH/DEE methods do not allow for the consideration of insulated or non-insulated partitions, conducting to the assumption of very conservative values, which, in consequence, leads to overestimate transmission heat losses to UnSp. DB-HE and RE2020 are quite similar in the variables under consideration; however, unfortunately, the situation where both INT-UnSp and UnSp-EXT partitions are isolated is missing in DB-HE. Considering that the thermal transmittance of the UnSp-EXT partition ($0.33 \text{ W}/\text{m}^2 \cdot \text{K}$) is less than half of the INT-UnSp partition ($0.75 \text{ W}/\text{m}^2 \cdot \text{K}$), and assuming that INT-UnSp partition is not insulated, DB-HE would lead to a different result ($b = 0.59$). In this situation, assuming the considered input data, the RE2020 method proved to be the most accurate. Despite having only a few options, to use in existing buildings, in this situation UNI/TS

matched the measured value on site. The measurements in Attic 1 were carried out in February, so it is believed that the effect of solar radiation was not significant. A final note to underline is that the EN ISO 13789 and BR 443 have provided very similar values. This may mean that the consideration of linear thermal bridges does not have a very significant weight in determining the value of the adjustment factor, b .

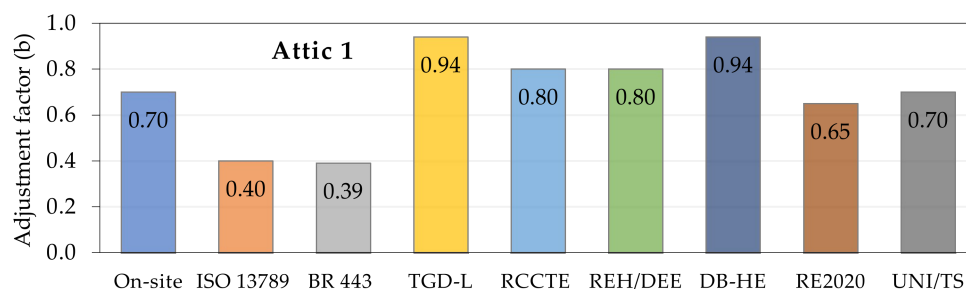


Figure 18. Comparison of the adjustment factor values (b) for Attic 1.

The results obtained for Attic 2 of Case Study 2 are shown in Figure 19. Attic 2 is a strongly ventilated UnSp. So, it was expected that the temperature was strongly conditioned by external environment. In fact, the measured b -value was 0.99, which means that the temperature is very close to the EXT temperature. As expected, being very conservative, the RCCTE, REH/DEE and UNI/TS methods assume a b equal to one for any strongly ventilated UnSp, as well as one which would match the on-site measured value. TGD-L, DB-HE and RE2020 have provided b -values quite similar to those determined based on EN ISO 13789 and BR 443. Once more, EN ISO 13789 and BR 443 provided very similar values, strengthening the idea that linear thermal bridges do not have a very significant weight in determining the value of b .

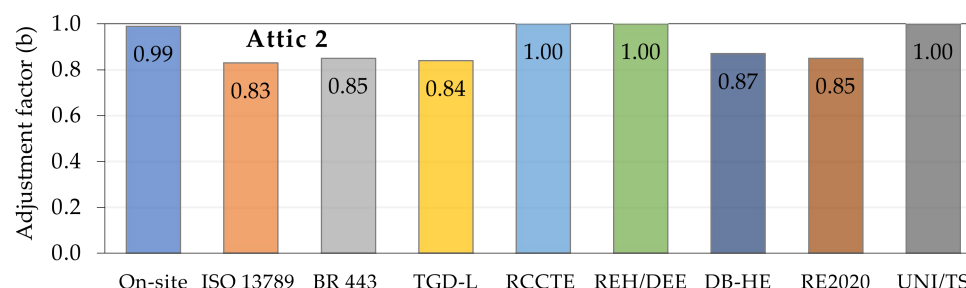


Figure 19. Comparison of the adjustment factor values (b) for Attic 2.

The obtained results for Attics 1 and 2 can be considered in line with those reported by Vučićević et al. [9] in a study published in 2018. In that study, Vučićević et al. [9] compared four different procedures to determine the adjustment factor when analysing the unheated attic of a High School in Belgrade to assess the energy performance of the building. The four different procedures include: (a) on-site measurement of temperatures for 11 days; (b) calculated from Standard EN ISO 13789; (c) simplified b -values set by Serbian regulation tables and (d) simulated by using TRNSYS software. The building date back to 1917 and the sloping roof is poorly insulated, presenting a U -value of $5.34 \text{ W}/(\text{m}^2 \cdot \text{K})$. The obtained results for the b -value were: on-site measured (0.97), standard (0.92), Serbian regulation (0.8), and simulated (0.94). After simulating the same building with different improved solutions for the slopping roof and a successive decrease in U -values from 5.34 to 0.24, a correspondent reduction of b -value was obtained from 0.94 to 0.73, leading the authors to conclude that the adjustment factor clearly depends on the roof insulation. The b -values of both EN ISO 13789 and dynamic simulation were consistent with the measured b -value on site, while the simplified b -value set by Serbian regulations tables deviate from the others, simply because it is a fixed value and does not account for the insulation or ventilation rate.

The results obtained for Garage 1, of Case Study 2, are shown in Figure 20. The on-site measured b -values for Garage 1 shows a very peculiar and unexpected result, being far below all the estimated values. After inquiring about the actual situation in which the readings took place, a possible justification can be pointed out. During that period, the inhabitants always kept the floor-standing fireplace in the kitchen in continuous operation. Well, it is an old wood-burning fireplace, with a base that rests directly on a granite stone at the base of the slab. The fireplace heated the slab, which in turn irradiates heat to the lower floor (Garage 1). On the other hand, the floor slab has no insulation, and the biggest thermal barrier is in the outer building envelope. This may justify why the temperatures of UnSp and INT are so close, with both being low due to poor insulation conditions.

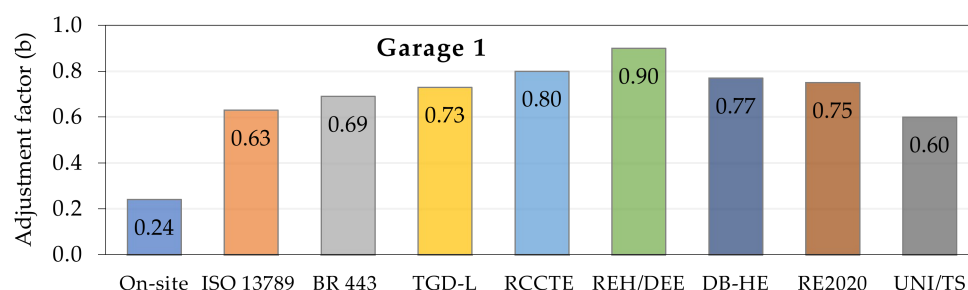


Figure 20. Comparison of the adjustment factor values (b) for Garage 1.

Comparing the simplified methods, it can be observed that, once more, the RCCTE and REH/DEE overestimated the b -value. DB-HE and RE2020 are in line with the results provided by EN ISO 13789 and BR 443. Again, there are no significant differences between the EN ISO 13789 and BR 443 results.

Both the EN ISO 13789 and BR 443 do not consider heat losses through the ground floor. It is believed that, in the case of Garage 1, the non-accounting losses through the ground floor will have had little influence on the calculated values, as the temperature of the garage averaged $13.95\text{ }^{\circ}\text{C}$, which is close to the ground temperature. On the other hand, as these spaces are located on the lower floor of the house and partially shaded in its surroundings, it is believed that the effect of solar radiation was of little significance.

Figure 21 shows the results obtained for Garage 2, of Case Study 3, consisting of a poorly ventilated UnSp with thermal insulation on the external envelope surrounding Garage 2. The on-site measured value of the adjustment factor, b , is very consistent to the ones obtained by RE2020, EN ISO 13789 and BR 443. The value obtained by DB-HE is slightly higher than the previous one. Again, the RCCTE and REH/DEE overestimated the b -value. The comparison between EN ISO 13789, and BR 443 confirms the previous idea that linear thermal bridges do not have a very significant weight in determining the b -value. Following the EN ISO 13789 and BR 443 statement, the heat losses through the ground floor were not considered.

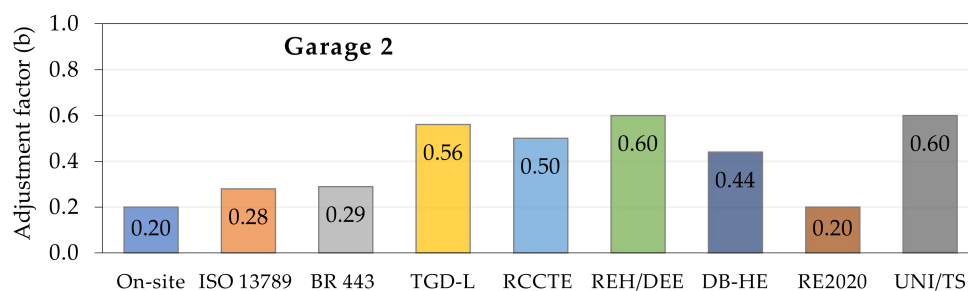


Figure 21. Comparison of the adjustment factor values (b) for Garage 2.

If the purpose is to simplify the procedures of EN ISO 13789, the overall obtained results have shown that BR 443 is a very effective alternative, reducing the time spent on

the calculation by not considering linear thermal bridges. In a second order of choice, the RE2020 method proved to be very effective, with an even lower calculation effort than BR 443. Except for Garage 1 of Case Study 2, where all methods failed, the RE2020 was the most consistent on estimation of the b-value measured on-site.

The REH/DEE, DB-HE, and RE2020 have a similar structure, with RE2020 being the most complete by considering four possible combinations of isolated and non-isolated UnSp partitions, in addition to a broader option for the A_i/A_e ratio, also considering different situations for the air ventilation rate. Even so, clarification is needed in the RE2020 method: (1) to better define what is considered an insulated or non-insulated partition; (2) to describe in more detail the different levels of ventilation, especially in garages. The DB-HE method admits three possible combinations of isolated and non-isolated UnSp partitions, but fails by not considering the situation where both INT-UnSp and UnSp-EXT partitions are isolated and narrow the options of the A_i/A_e ratio. The REH/DEE is even more restrictive because it does not account for any insulated and non-insulated partitions, presenting an even more limited option for the A_i/A_e ratio; additionally, the ventilation rate is described in a very subjective manner.

Both RCCTE and REH/DEE are conservative methods and tend to significantly overestimate the b-value. The UNI/TS has limited options and is used in existing buildings.

6. Conclusions

In the present study, the on-site assessment of the adjustment factor (b) was carried out in three different dwellings, involving four different unheated spaces (UnSp). The experimentally obtained values were compared with those based on simplified methodologies, namely EN ISO 13789, BR 443, TGD-L, RCCTE, REH, DEE, DB-HE, RE2020, and UNI/TS. The following conclusions can be drawn from this study:

- (1) EN ISO 13789 and BR 443 have provided very similar values. It can be concluded that the consideration of linear thermal bridges does not have a very significant weight in determining the value of the adjustment factor (b).
- (2) If the purpose is to simplify the procedures of EN ISO 13789, the overall obtained results have shown that BR 443 is a very effective alternative, reducing the time spent on the calculation by not considering linear thermal bridges. In a second order of choice, the RE2020 proved to be very effective, with an even lower calculation effort than BR 443.
- (3) RE2020 was the most consistent on estimation of the on-site measured b-value. Even so, clarification is needed in the RE2020 method: 1) to better define what is considered an insulated or non-insulated partition; 2) to describe, in more detail, the different levels of ventilation, especially in garages;
- (4) DB-HE has a very similar structure to the RE2020 method, concerning the variables under consideration, but it fails by not considering the situation where both INT-UnSp and UnSp-EXT partitions are isolated and narrow the options of the A_i/A_e ratio.
- (5) REH/DEE also presents a similitude to RE2020 and DB-HE, however, by, being even more restrictive, not accounting for any insulated and non-insulated partitions, presenting an even more limited options for the A_i/A_e ratio and describing the ventilation rate in a very subjective manner.
- (6) RCCTE and REH/DEE significantly overestimate the adjustment factor values of the UnSp compared to the other analysed methods, except for strongly ventilated UnSp. These methods do not allow for the consideration of insulated or non-insulated partitions, conducting to the assumption of very conservative values, and overestimating transmission heat losses to UnSp. This can lead to less experienced designers to adopt less suitable constructive solutions for the building envelope, since in this particular case, the b-value will determine the minimum U-value requirement for the envelope partitions.
- (7) TGD-L is a simplification of BR 443 procedure, but it has shown to be less consistent than RE2020 in the estimation of the adjustment factor. It takes into account the

U-value of the partition between INT and UnSp, as well as the thermal resistance conferred by UnSp. The thermal resistance of the UnSp, such as garages, conservatory-type sunroom, stairwells, and access corridors in flats are well-defined, but it is less clear when dealing with the attics.

- (8) The UNI/TS is for application in existent buildings and has very limited options if the purpose is for use in new buildings.
- (9) Uncertainty of the estimation of the hourly air renewal rate of the UnSp, by air exchange with outdoor air, has a significant impact on the accuracy of the analysed methods.
- (10) The thermal characteristics of the elements that separate the INT from UnSp and the UnSp from EXT are relevant for estimating the UnSp adjustment factor (b). Accounting only for the areas of the elements that separate the INT from UnSp and the UnSp from EXT results in a worse estimate of the adjustment factor (b).
- (11) The fact that the heat transfer coefficient through the garage floor was not accounted for in EN ISO 13789 and BR 443 does not seem to have affected the accuracy of the adjustment factor estimate.
- (12) For strongly ventilated UnSp, the existence of thermal insulation in the outer envelope of UnSp has no significant effect on the adjustment factor (b).

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