

The effect of the presence of thermal bridges related to roof insulation on annual energy consumption for two different climatic zones in Morocco

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Abstract. Since its putting into use in 2015, the Thermal Regulations for Construction in Morocco (RTCM) have defined six (related to the Earth's weather) zones and set consumption to be respected for each zone. In this study, we calculated the once-a-year energy needs of uninsulated buildings. We then studied the effect of roof insulation using two materials: expanded polystyrene and extruded polystyrene. Finally, we evaluated the thermal bridges effect on total energy use. The study focused on two zones: Zone 1, with a humid climate, and Zone 3, which is hot and dry one. The results show that uninsulated buildings remain acceptable in Zone 1 but far go beyond the limits set for Zone 3, where insulation becomes extremely important. Expanded polystyrene proved to be the most effective, reducing energy use by 67% in Zone 1 and 32% in Zone 3. In zone 1, thermal bridges result in a 6% increase in energy consumption; in zone 3, this increase rises to 13–16%. Overall, zone 1's difference with RTCM-required items is roughly 3%, while zone 3's is +33%. The overconsumption caused by thermal bridges ranges from 8.2% to 16.3% in zone 1 and from 13% to 16.3% in zone 3.

Keywords: insulation, annual consumption charges, dynamic thermal simulation, thermal bridge, thermal regulation.

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Nomenclature

Symbole	Désignation	Unité
λ	Conductivité thermique du matériau	$\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$
ρ	Masse volumique	$\text{kg}\cdot\text{m}^{-3}$
C_p	Capacité thermique massique	$\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$
U	Coefficient de transmission thermique	$\text{W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$
Ψ	Coefficient linéique de pont thermique	$\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$
E	Épaisseur de la couche	M
h_i	Coefficient d'échange thermique intérieur	$\text{W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$
h_e	Coefficient d'échange thermique extérieur	$\text{W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$
φ_T	Flux thermique total	W
ΔT	Différence de température	K
Qann	Consommation énergétique annuelle	$\text{kWh}\cdot\text{m}^{-2}\cdot\text{an}^{-1}$

1 Introduction

Despite significant efforts in recent years to incorporate innovative technologies addressing energy consumption and climate change challenges, many regions in Morocco still grapple with indoor heating issues in residential and tertiary structures. Construction, which constitutes 33% of the final energy consumption in Morocco, is experiencing rapid growth [1-4]. In this regard, various numerical and experimental studies on insulation as a passive storage element in the building envelope and their impact in thermal bridge have been addressed. For example, four methods for accurately modelling heat transfer through a thermal bridge and smoothly integrating it into building energy simulation programs were presented by Julien Quinten et al. [5] and tested on basic 1D cases. The findings showed that a combination of the harmonic method and the structure factor method is the best strategy. When compared to the conventional analysis of thermal bridges, this method produced extremely accurate and better results when tested on a 2D thermal bridge positioned between the ground and the external wall.

H. Viot et al. [6] provided a critical scientific retrospective on thermal bridge calculation methods. In compliance with the European norm, they conducted steady-state simulations under dynamic settings. The findings demonstrated that designing workplace values using

conventional techniques frequently results in serious mistakes. The models that concentrated the entire mass of the wall and took into consideration the inertia of the post were found to be more accurate than more conventional layouts. Julien Quinten et al. [7] introduced an approach based on calculations of thermal resistance, heat capacity, structure factors, and an objective function employing harmonic heat flux characteristics. The results demonstrated that the evolution of heat flux through the thermal bridge substantially approximated the corresponding equivalent wall when this method was applied to three 2D features. The inaccuracy on the integral value of the heat flow was determined to be less than 1%, in contrast to a conventional 1D assessment where the error average ranged from 6 to 28 times larger.

F. Aguilar et al. [8] presented a novel technique for changing a wall's thermal characteristics to three equivalent layers while accounting for the temperature distribution over the thermal bridge in a steady-state thermal conduction scenario. The possibility of using this method to develop energy simulation tools was considered. The study indicates that the thermal flux through the thermal bridge may be underestimated by 25% if it is not considered. However, modeling the thermal bridge without accounting for its thermal inertia resulted in a delayed thermal flow response. However, the corresponding wall method simulation yielded almost the same response to the actual dynamic performance of the thermal bridge. To meet the growing need for thermal insulation and to statistically assess heat losses across thermal bridges, Laurent Zalewski et al. [9] carried out a study assessing the thermal efficiency of complex building walls. A light industrial building with a metal frame, insulating material between the metal trusses, steam and water barriers, and interior and external facings was the subject of the study. The study used an actual experimental method to quantify features of heat loss through the envelope using infrared thermography to visualize thermal bridges. The results demonstrated that heat flux measurements may be carried out locally and with ease using appropriate flow meters, employing a three-dimensional numerical approach for prediction. Interestingly, it was discovered that heat losses in front of the steel frame were twice as large as those in other locations.

The effect of dynamic modelling of thermal bridges on the energy performance of multi-unit residential buildings with high thermal mass in Canada's cold climates was investigated by Hua Ge et al. [10]. According to simulation results, adding thermal bridges reduced the annual energy demand for space cooling by 8 to 26% and raised the annual energy demand for space heating by 38 to 42%. It was discovered that the quantity and quality of thermal bridges affected their dynamic impact on energy performance. Furthermore, the comparable U-value approach and the equivalent wall method may underestimate the yearly energy requirement for space heating by up to 13% and 10%, respectively. Nevertheless, enhancing the connection's specifics decreased the disparity between dynamic 3D modelling and the equivalent U-value method to less than 3%.

The thermal bridges from the outside walls' offset windows were investigated by Mohammed Ibrahim et al. [11]. The results demonstrated that the windows compensate for the percentage of energy load of the thermal bridges compared to the total load of the house, which represents approximately 2 to 8% depending on whether the external walls have internal insulation or not, and that the application of 1 cm and 2 cm of the coating on these thermal bridges reduces the energy load of compensation of the windows by approximately 24 to 50%.

By using an average U value in a 1D energy simulation program for the entire building a technique known as the method of equivalent U value Fuad Baba et al. [12] examined the effect of thermal bridges on the energy performance of buildings. While considering their influence on the overall thermal transmittance of envelope details, this approach disregarded the thermal inertia effect of thermal bridges. Simulation results show that the equivalent U value method underestimated annual charges for the intended building by 2.8 to 4.4%. Most

existing articles focus on general climatic circumstances, despite the expanding area of literature embracing construction energy performance and thermal bridges. In Morocco, questions about the RTCM's applicability are still limited, particularly when it comes to dynamic simulations and the precise integration of thermal bridge effects. The results that are presented typically consider linear heat deficits at junctions and assess compliance with RTCM using simplified methods based on total U-values. Similarly, even though numerous studies have shown how important thermal bridges are for heating and cooling needs, their impact is rarely measured in connection to national regulatory thresholds or across Moroccan climatic zones. Thus, this work is distinctive in that it directly compares the results with RTCM standards for two different climatic zones while integrating dynamic thermal modelling with a thorough thermal bridge assessment. This method shows the shortcomings of current regulatory evaluations when thermal bridges are disregarded and offers a more accurate assessment of annual energy use. In addition to being the first to analyze the effects of thermal bridges on consumption loads, the research seeks to determine how roof insulation influences annual consumption loads. This study is noteworthy for its innovative approach of comparing results with Morocco's mandated thermal building rules, taking into account two different climatic zones: a hot, dry region and a humid zone. By shedding light on the relationship between consumption loads and roof insulation and thermal bridges, our research provides fresh insights into energy saving measures appropriate for different climatic circumstances. This will significantly improve Morocco's use of sustainable building techniques.

2 CLIMATE ZONING

For a simple and efficient implementation of the new regulations, the zoning map features six climatic zones that are confined in accordance with the administrative boundaries. The following cities serve as meteorological representations of these zones: Agadir is the first zone; Tangier is the second; Fez is the third; Ifrane is the fourth; Marrakech is the fifth; and Errachidia is the sixth. The map depicting Morocco's climatic zone system for temperature control is shown in Fig. 1 (National Weather Directorate 2011).

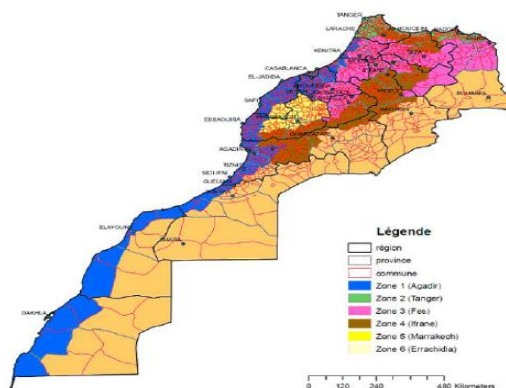


Fig 1. Climate zoning in Morocco

3 Description of the building

Different construction materials were used in the design of the TRNSYS architectural models. The basic construction that is being studied is a room with a single temperature zone that is set up as follows:

The exterior walls are made of double hollow bricks with a 10 cm gap between them. The exterior is rendered with cement, while the interior is rendered with plaster.

Concrete with a thickness of 30 cm makes up the low floor.

The ceiling is made up of three centimetres of tile, two centimetres of mortar, and twenty-five centimetres of strong concrete.

Double glazing covering 2 m² is a characteristic of the south facade. Heating is activated when the inside temperature falls below 20 °C, while air conditioning is activated when the summertime temperature rises beyond 26 °C. The rates of ventilation and infiltration are fixed at 0.6 m³/h. A microprocessor with a color display (230 W), artificial lighting (10 W/m²), and two occupants working light or seated are all represented by internal gains. Table 1 lists each material's specific thermo-physical characteristics.

Table 1. Thermo-physical proprieties of materials.

Materials	Thermal conductivity [W/m.K]	Thermal capacity [J/kg.K]	Density [Kg/m ³]
Hollow brick	0.19	741	918
exterior plaster	1	1000	1700
plaster coating	0.8	1000	800
expanded polystyrene	0.032	1450	32.5
Extruded polystyrene	0.047	1450	14
Concrete	2	1000	2450
Floor tile	1.3	840	2300
Mortar	1.8	1000	2500

4 Methodology

This study will first involve comparing the annual energy consumption of a non-insulated building with regulatory requirements through numerical simulations using the TRNSYS software. Subsequently, we will examine the impact of roof insulation on energy consumption costs by comparing the results with regulatory benchmarks.

This will involve simulating scenarios outlined in Table 2. Finally, we will incorporate linear heat losses attributed to thermal bridges into the dynamic thermal calculations in TRNSYS and assess their influence on energy performance.

Table 2. The studied scenarios.

Scenarios	Composition of the roof from outside to inside	coefficient of thermal transmission [W / (m ² .K)]
S1	tile (2 cm) -mortar (3 cm) -heavy concrete (25cm)	3.087
S2	tile (2 cm) -mortar (3cm) -expanded polystyrene (6 cm) -heavy concrete (25cm)	0.192
S3	tile (2 cm) -mortar (3 cm) -extruded polystyrene (6 cm) -heavy concrete (25cm)	1.425

The analysis of thermal bridges is conducted using the ULYS software, which facilitates the calculation of the linear loss coefficient (ψ) through relation (1) and provides insights into the temperature distribution and heat fluxes within the junctions. The thermal transmission coefficient for each element is determined through the calculation outlined in relation (2).

$$\psi = \frac{\varphi T}{\Delta T} - \sum_{i=1}^N U_i L_i \quad (1)$$

$$U = \frac{1}{\frac{1}{hi} + \frac{1}{he} + \sum \frac{ei}{\lambda} + \sum Ri} \quad (2)$$

5 Validation with literature results

We carried out extensive experimental validation to guarantee the dependability of our numerical model. In this work, we investigated a 4 cm-thick semi-infinite block made of an energy-efficient material (EEM) at a fusion temperature $T = T_m = 28^\circ\text{C}$. We applied a constant temperature at the western boundary that was higher than the fusion temperature ($T_L = 38^\circ\text{C}$) in order to replicate realistic conditions, while the other sides were regarded as adiabatic. We conducted a thorough comparison between our numerical model and an established experimental solution for this problem using only thermal conduction through the EEM. This validation comprised solving the problem experimentally and then using specialized computational software to rigorously compare the outcomes produced by both models. Our confidence in our numerical model's ability to accurately predict the thermal behavior of the energy-efficient material under comparable conditions has increased because of this validation process, which enabled us to verify its accuracy and consistency against a well-established experimental solution. The temperature variation of the inner face of the hollow brick with PCM is shown in the following figure, which compares our numerical results with those from the experimentation [12]. With a mean difference of 0.4°C and an average error of 1.5%, the comparison of the two models shows a numerical curve that is extremely similar to the experimental curve. This can be explained by the experimental setup's natural convection and the fact that, while our numerical study assumes two dimensions, the experimental setup incorporates a third dimension. Overall, we find that our numerical model can accurately predict outcomes that are more in line with reality.

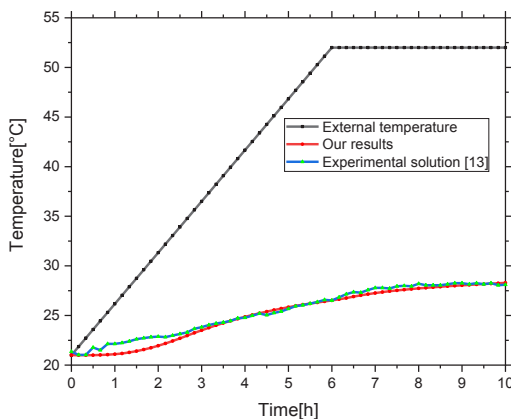


Fig 2. the comparison between our numerical results and those obtained in the experimentation [12].

6 Results

6.1 Annual heating and cooling requirement and comparison with RTCM values for zones 1 and 3

In Fig. 3, the annual heating and cooling demands are depicted for two climatic zones: a hot and dry climatic zone (Zone 3) and a humid zone (Zone 1). The graph also illustrates a comparison between these loads and the requirements specified by the RTCM for an uninsulated residential building.

The graph reveals that, for Zone 1, an uninsulated building is deemed acceptable in terms of annual consumption, showing a 3% reduction compared to the RTCM stipulated value. However, for Zone 3, an uninsulated building is not recommended according to regulations, surpassing the required value by 33% in terms of annual consumption charges.

Based on these findings, the subsequent step involves insulating the roof with two insulation layers, which will be discussed in the following section.

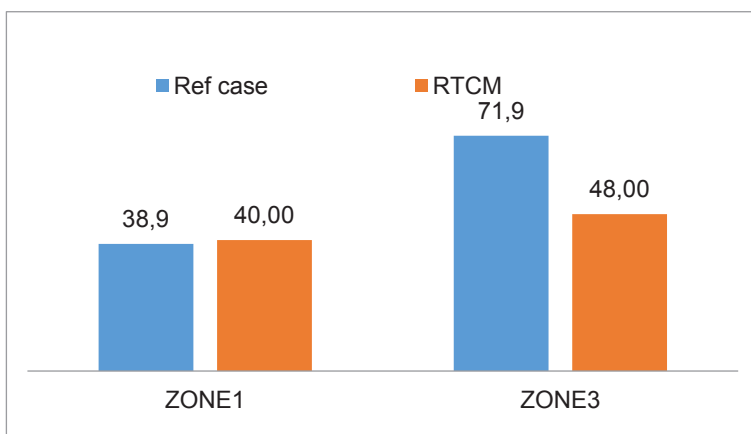


Fig 3. Annual Heating and Cooling for Zones 1 and 3

6.2 Impact of roof insulation on annual consumption and comparison with RTCM values for zones 1 and 3

The annual consumption of roof insulation in zones 1 and 3 for the different scenarios under study is shown in Fig. 4, along with a comparison to legal requirements. In both climatic zones, expanded polystyrene (S2) roof insulation works better than extruded polystyrene (S3). In comparison to RTCM, Scenarios 2 and 3 show reduction rates of 67% and 62% for Zone 1 and 32% and 25% for Zone 3, respectively. Expanded polystyrene insulation is therefore recommended for roofs in both climatic zones because of its low heat transmission, which leads to lower loads in comparison to Zone 1 and Zone 3 regulations. The regulations do not address losses related to thermal bridges, even though they set requirement values for losses related to load-bearing components of the structure. As discussed in the following section, which looks at how thermal bridges affect annual consumption charges, it is important to take these losses into account when performing dynamic thermal calculations. The coefficients of thermal transmission (U) and linear heat losses (ψ) for each scenario are displayed in Table 3.

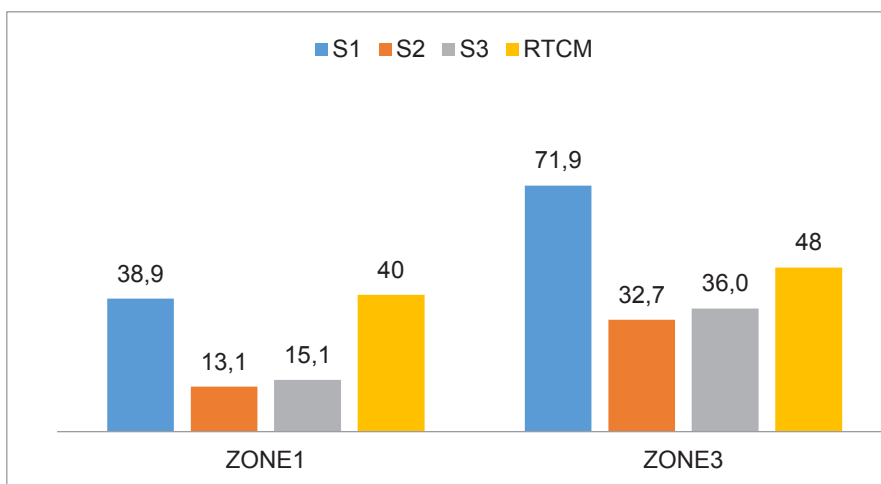


Fig 4. Impact of Roof Insulation on Annual Consumption and Comparison with RTCM Values for Zones 1 and 3

Table 3. The coefficient of linear heat losses ψ and the coefficient of thermal transmission U

	ψ [W/(m.K)]	U [W/m ² .K]
S1	0.529	3.087
S2	0.294	0.192
S3	0.318	0.425

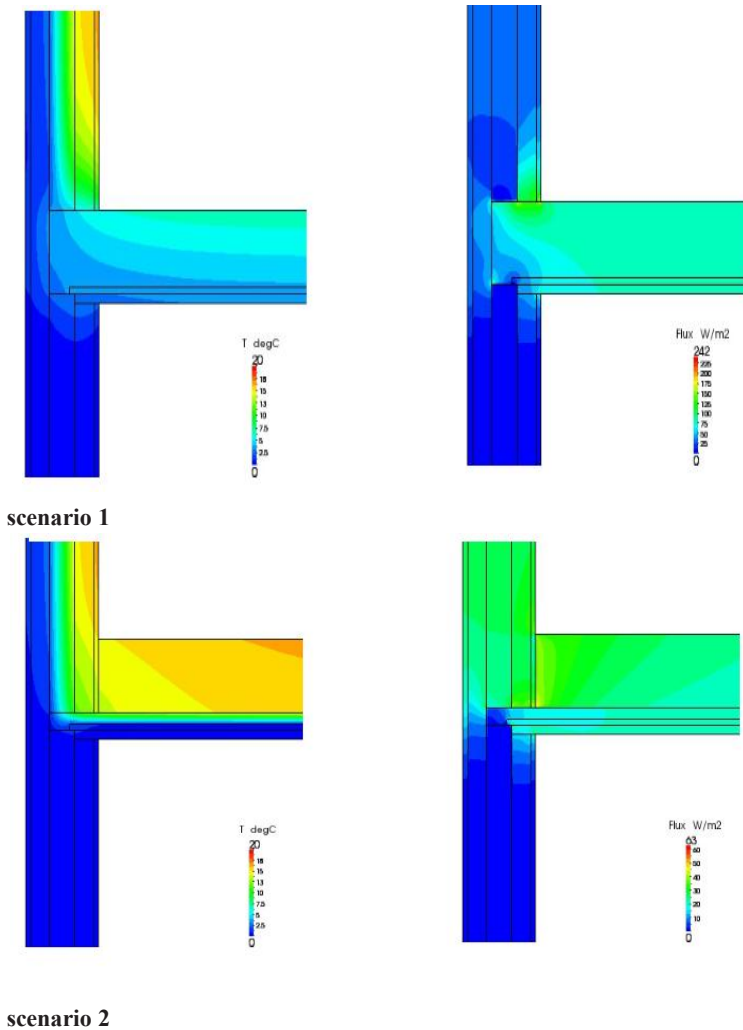
The table's findings demonstrate that the losses caused by the wall-roof connection increase with decreasing roof thermal transmission. The best outcome in our study is scenario 2, which

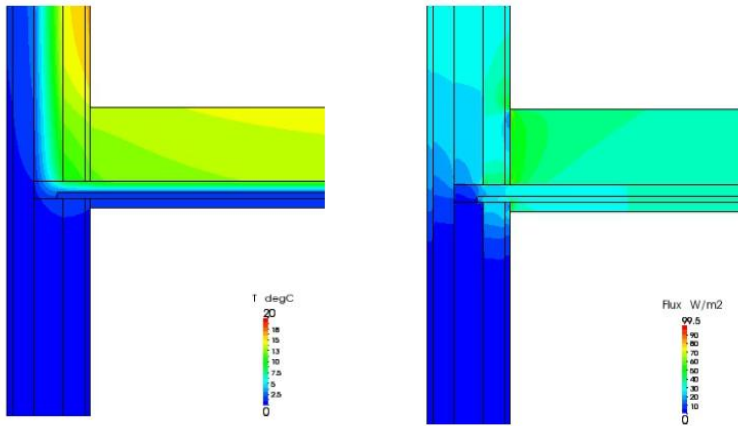
produces the fewest linear losses per thermal bridge and has the least amount of thermal transmission.

6.3 Flow and temperature maps in thermal bridges

A thorough understanding of the distribution of temperatures and heat fluxes, particularly within the roof-to-external wall connection, is given by these visual representations in Figures 5. The thermal properties in these configurations are particularly evident in the temperature intervals of [5.13] °C, [13.15] °C, and [10.15] °C for scenarios 1, 2, and 3, respectively. Furthermore, the different levels of heat transfer in scenarios 1, 2, and 3 are shown by the heat flux intervals of [75,150] W/m² [20.40] W/m² and [40.25] W/m², respectively.

These maps show a clear pattern that highlights the tendency for the temperature of the thermal bridge to rise while the heat flux fluctuates as the thermal transmission in the roof decreases. This pattern is especially noticeable in scenario 2, highlighting how crucial good roof insulation is to reduce thermal bridges and maximizing energy efficiency.





scenario 3

Fig 5. Temperature and flow maps for scenario 1,2 and 3.

Figure 8 shows the annual consumption charges for zone 1, both with and without thermal bridges included in the computations, as well as a comparison with RTCM. According to the findings, taking thermal bridges into consideration increases annual consumption by 8.2%, 1.8%, and 1.2% for scenarios 1, 2, and 3, respectively. To account for losses caused by thermal bridges, it becomes necessary to add an extra 5.63% gain for this specific zone, above the amount required by regulations. The extra value is almost 2%, even in the best case (S2). This emphasizes how important it is to account for thermal bridges in the computations to guarantee a more accurate depiction of yearly consumption charges in zone 1.

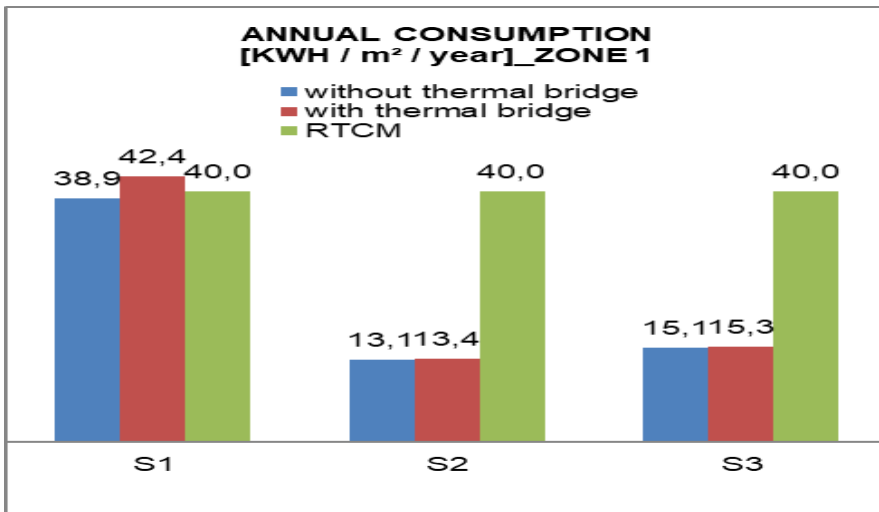


Fig 6. impact of thermal bridges on annual consumption for zone 1

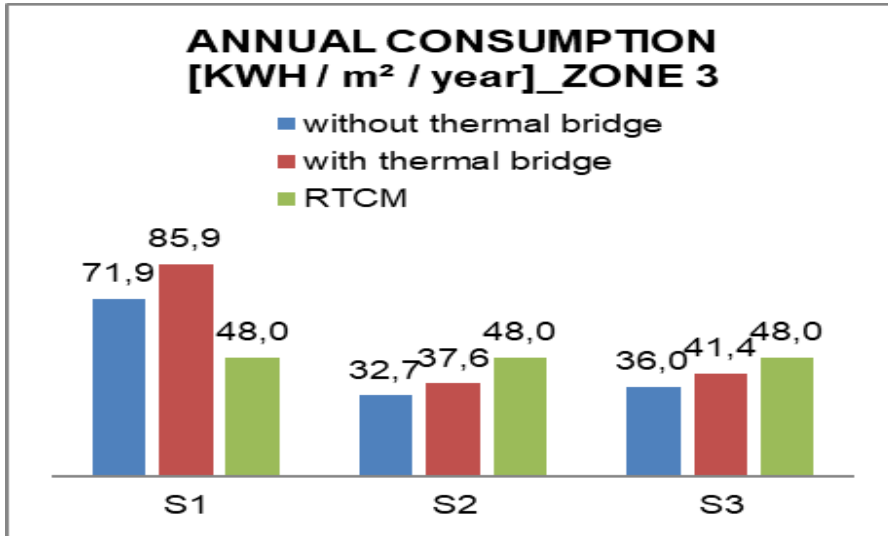


Fig 7. impact of thermal bridges on annual consumption for zone 3

Figure 9, the annual consumption charges are depicted, considering and not considering thermal bridges in the calculations, along with a comparison to RTCM for zone 3. The findings reveal that factoring in thermal bridges leads to an increase in annual consumption by 16.3%, 13%, and 13.1% for scenarios 1, 2, and 3, respectively.

When thermal bridges are considered in calculations, scenarios 2 and 3 show a negligible difference in the increase of loads in Zone 3, which is described as hot and dry. The effects of both kinds of insulation are comparable, requiring an additional value of about 13%.

7 Conclusion

In this study, we performed a dynamic thermal calculation for an uninsulated building and compared it with Moroccan thermal building regulations, considering two different climatic zones: one hot and dry and the other humid. We then used two types of insulation to examine the effect of roof insulation on annual consumption loads. Lastly, we investigated the impact of thermal bridges on consumption loads and contrasted the results with RTCM for Zones 1 and 3.

According to the results, an uninsulated building with a 3% lower consumption charge than RTCM is advised for Zone 1. However, because the loads in Zone 3 are 33% higher than what is required by regulations, insulation becomes essential. Expanded polystyrene roof insulation proved to be the best option among different scenarios, yielding reduction rates of 67% and 32% for Zone 1 and Zone 3, respectively, in comparison to regulations.

Thermal bridge analysis revealed that taking them into consideration resulted in gains of 16.3%, 13%, and 13.1% for Zone 3 and 8.2%, 1.8%, and 1.2% for scenarios 1, 2, and 3 in Zone 1. To prevent underestimating annual consumption charges and their effect on building thermal comfort, the study also highlighted the correlation between increased insulation and decreased losses through thermal bridges.

Looking ahead, our future work will explore the impact of linear and point thermal bridges for both insulated and non-insulated buildings across various climatic zones.

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