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The role of thermal insulation layers and the integration of solar energy in temporary heating systems

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ABSTRACT

This paper examines thermal insulation strategies for building walls and the integration of solar heating systems to improve the performance of temporary heating systems in residential buildings in Kosovo. A two-story house was used as the case study, simulating four different scenarios of thermal insulation layer placement in the walls with different capacities of the heating system. The proposed thermal balance method of the building takes into account the arrangement of thermal insulation layers and their impact on the building's energy savings. The results indicate that external insulation offers the best balance between heat retention and energy efficiency, while internal insulation enables faster heating and a shorter time to reach the desired temperature. Under low-temperature conditions, solar energy was analyzed and integrated as an additional source to enhance the heating system capacity and reduce electricity consumption. Simulation results demonstrate further improvement in system performance, enabling optimized operating schedules and a significant reduction in energy consumption.

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1. INTRODUCTION

The need for sustainable and efficient solutions for heating buildings has become increasingly urgent due to rising energy prices, climate crises, and demands to reduce carbon emissions [1]. Many designers use simplified thermal balance models in building heating and in heating, ventilation, and air conditioning (HVAC) system designs. These solutions are often designed with a focus on simplicity of installation and low initial costs, while neglecting the dynamic aspects of the building's thermal exchange with the environment [2]. One of the main problems identified in the practical use of these systems is the lack of consideration of the thermal inertia of the walls and the heat accumulated in the structure during the dimensioning of the heating system. Many researchers base calculations of the required heat only on the analysis of steady-state thermal losses through building elements, without considering the thermal capacity of the walls and the time needed to reach a steady-state thermal state [3]. As a result, users complain of feeling cold even after several hours of heating from the system, especially in winter periods when outside temperatures are low, as the heating system does not have the capacity to compensate for the "thermal filling" of the building structure. The impact of cold, in addition to human thermal comfort, also has consequences for health. Complaints are related to the high price of electricity; therefore, to save energy, the heating system is interrupted during periods when activities are not taking place. Currently being discussed are spaces such as offices, schools (e.g., heating turned off from 4:00 PM to 8:00 AM), commercial premises, markets, apartments, houses (e.g., without heating from 8:00 AM to 4:00 PM), holiday homes, event halls, warehouses, garages, workshops, and similar facilities. Such a case was observed in a two-story building with a volume of about 900 m³, where the heating system with an installed power of 20 kW failed to satisfactorily heat the environment for 10 hours, in conditions of an external temperature of -12 °C, despite the external insulation of the walls. "The problem lies in the designed heating system, which, even at full capacity, does not compensate for the heat losses, resulting in the desired (designed) indoor temperature not being reached for several hours. There are often requirements from designers and installers that the heating system must be turned on at least 24 hours before it is needed. This implies unnecessary energy consumption during that 24-hour period. Furthermore, practical challenges arise, such as who will activate the system if the users are away, or how to manage it if there is no remote electronic access to control the equipment.

Therefore, the study aims to explore methods that incorporate both technical and economic analyses in the design of the heating system, based on a thermal balance that accounts for heat accumulation in walls, energy savings through the application of insulating layers, and the integration of renewable energy sources, as well as analytical solution methods and simulations for parameter optimization. For this reason, in order to analyze the contribution of heat accumulation in walls, it is essential to consider unsteady-state heat conduction in walls during the design of temporary heating. This process is described by the unsteady heat conduction equation, as in (1) [4]-[8].

$$\rho c_p \frac{dt}{d\tau} = \lambda \left[\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2}\right] \tag{1}$$

Where τ – time (s), t – temperature (°C), λ – thermal conduction (W/mK) [9], ρ – density (kg/m^3), c_p – specific heat (kJ/kgK), x,y,z – coordinates in space (m).

In this context, thermal inertia plays a crucial role, as it reflects the ability of the walls to store and release heat over time. The greater the thermal inertia, the more energy is initially required for heating; however, it also ensures improved temperature stability over time [3]. An important indicator of this behavior is the thermal time constant T (with units of s), which defines the time needed to achieve a specified degree of thermal equilibrium between the building structure and the indoor air. The time constant, which represents a structure's ability to respond to external thermal variations, depends directly on the thermophysical properties of the wall - such as thermal capacity, conductivity, and density - and significantly influences both the time delay and the attenuation factor of the thermal flux amplitude. As pointed out by Asan and Sancaktar [10], increasing the thermal capacity and wall thickness leads to a significant increase in this constant, improving the overall thermal performance of the building under dynamic conditions. The need to include non-stationary effects and heat accumulation becomes particularly important in buildings with partial daily heating use, where the heating system must react quickly and accurately.

Simultaneously, to minimize heat losses and improve the building's thermal efficiency, the implementation of suitable thermal insulation layers is of critical importance. The selection and arrangement of materials directly affect the heat transfer coefficient (k) and the thermal stability of the building [9]. This allows modeling of heat interaction with walls as a function of time and improves the calculation of real heating requirements [11]. Also, the integration of solar energy as an auxiliary source of heating represents one of the most promising approaches to reduce electricity consumption and increase the energy independence of heating systems [11]. Solar collectors can be integrated to partially meet the heating demand, contributing to the development of a hybrid and more sustainable heating system [12]. Thus, the integration of solar energy as an auxiliary source can significantly contribute to reducing the initial thermal load and improving the thermal response rate of the indoor environment [13]. Furthermore, contemporary building automation systems integrate sensors and control units designed to optimize the performance of the heating system based on real-time indoor and outdoor environmental conditions [14].

Accordingly, the aim of this study is to achieve energy savings by appropriately designing and positioning insulation layers and integrating solar energy systems. These measures contribute to the optimal sizing of the heating capacity and enable the automated control system to reach the desired indoor temperature within the required time frame.

2. METHOD

2.1. Thermal inertia

Thermal inertia refers to the capacity of a material or structure to absorb and store heat, thereby moderating rapid temperature fluctuations in the surrounding environment. It is strongly associated with the material's physical properties [15]. In the case of a flat wall, the simplest and most typical element used in buildings of all types, the thermal inertia coefficient can either be found in the literature or determined through (2).

$$D = 0.27 \sum_{i=1}^{n} \frac{\delta_i}{\lambda_i} \sqrt{\lambda_i c_i \rho_i} \tag{2}$$

Where: λ_i – thermal conductivity coefficient (W/mK), c_i – specific heat capacity (J/kgK), ρ_i – wall layer density (kg/m^3), and δ_i – wall thickness (m).

This parameter indicates the rate at which a material responds to thermal variations, specifically the speed at which heat propagates through it. A lower value of D indicates a higher thermal inertia, implying that the material responds more slowly to temperature changes, i.e., it heats up and cools down at a slower rate [16]. In scenarios involving temporary or intermittent heating, disregarding the thermal inertia of building envelopes, particularly the walls, can result in a substantial miscalculation of the initial heating energy requirements, as a considerable portion of the supplied energy is initially absorbed by the building mass before reaching thermal comfort levels. This phenomenon explains why occupants often report feeling cold for several hours after the heating system is turned on, especially during cold winter days. The thermal inertia of the building's external elements plays a crucial role in seasonal energy performance. Materials with high thermal capacity and low thermal conductivity can contribute to stabilizing indoor temperatures, thereby reducing peak cooling and heating loads. According to Evola and Lucchi [17] this dynamic behavior can be translated into a heat flux delay of several hours, depending on the thickness and composition of the wall.

2.2. Thermal time constant

The time constant represents the characteristic time required for a structure to reach approximately 63% of the temperature change following a thermal disturbance (such as heating system activation). It is approximately calculated as (3).

$$T_a = \frac{C_a}{K_m} = \frac{\rho_a V c_a}{kA} \text{ - for the air, and } T_m = \frac{C_m}{kA} \text{ - for the wall.} \tag{3}$$

Where C_a - thermal capacity of air (J/K), C_m - thermal capacity of the wall (J/K), k - overall wall heat transfer coefficient (W/m^{2}K); A – the surface area of the wall through which heat is transferred (m^2), V - the volume of the structure through which heat is transferred and stored (m^3).

In practical applications involving complex structures and actual buildings, the time constant may range from 5 to 15 hours, influenced by factors such as material properties, insulation quality, and the overall building volume [11]. The thermal inertia of building walls varies with material, thickness, and thermal capacity. For example, walls with enhanced thermal mass can have a thermal delay of 10–12 hours and significantly reduce heat flux, directly affecting heating and cooling energy needs [18].

2.3. Heating system on and off times

Unlike continuous heating systems that operate steadily to maintain indoor temperature, intermittent heating systems activate only during specific periods, making the building's thermal inertia a key factor in the time required to reach the desired temperature and thermal comfort. Therefore, determining the optimal heating system activation time is essential for sizing the heating capacity with solar energy integration, minimizing energy consumption, maintaining thermal comfort, and avoiding heating delays [19]. In high thermal inertia structures, the transient conduction model shows that the time required to reach a new thermal state is significantly longer due to the high heat storage capacity and resistance to rapid temperature changes. As noted by Nicol *et al*. [20] this thermal behavior directly affects heating rates and necessitates adaptive strategies for temperature and thermal comfort management. The use of the electrical analogy, as proposed by Fraisse *et al*. [21] provides a simplified and accurate way to describe this process, showing that buildings with high thermal inertia require significantly longer response times to changes in thermal load. Therefore, in such contexts, it is recommended that the heating system be activated on a preset schedule at least 3–4 hours before actual occupancy or combined with an automatic early start strategy based on weather and thermal load forecasting [22]. In continuous heating, the system can be turned off when the indoor temperature reaches the set point or based on usage patterns (e.g., at night or during absence). For intermittent heating, optimal shut-off should occur earlier so that stored heat in the structure continues to release energy, maintaining acceptable temperatures for a period. This relies on the heat flux reversal phenomenon from the structure to the indoor environment (thermal lag effect) [23]. In practice, this means the system can be turned off 30–90 minutes earlier without compromising comfort, depending on the structure's thermal mass [24].

2.4. Heat required for heating

In continuous heating systems, the goal is to maintain indoor comfort conditions consistently. To achieve this, the required heating power ($\dot{Q}_n$) must balance heat losses through transmission (occurring via building envelope elements such as walls, windows, floors, and roofs) and ventilation (due to air exchange with the outdoor environment). This can be described by (4).

$$\dot{Q}_n = \dot{Q}_V + \dot{Q}_T \quad (4)$$

Where: $\dot{Q}_n$: thermal power demand for heating (W), $\dot{Q}_T$: the rate of heat transfer through the walls (W), $\dot{Q}_V$: heat losses due to ventilation (W).

The use of these equations forms the basis for heating system sizing in numerous European and international standards, including ISO 13790 and DIN V 18599 [25], [26]. In continuous heating, these values are static and do not account for the effects of thermal inertia or heat storage in the walls, unlike in intermittent heating scenarios [27]. For practical applications and engineering-based heating system sizing, references such as [28] provide detailed methods for energy auditing and accurate consumption calculations. Furthermore, the importance of the thermal capacity of structures and the impact of thermal mass in construction have also been addressed in experimental studies on various thermally activated structures [29]. For more realistic and advanced calculations, approaches such as dynamic energy performance modeling are used, considering thermal mass, heat storage, and the building's thermal response time [30].

The heating energy required for intermittent heating of a building ($\dot{Q}_n$) includes three main components of heat losses ($\dot{Q}_V$ – heat from ventilation, $\dot{Q}_T$ – the rate of heat transfer through the walls, and $\dot{Q}_{Am}$ – heat flow related to thermal energy accumulation in walls, as described in the technical literature [31], [32].

$$\dot{Q}_n = \dot{Q}_V + \dot{Q}_T + \dot{Q}_{Am}, W \quad (5)$$

This calculation model is particularly suitable for situations requiring short-term heating (such as temporary heating of infrequently used buildings) and reflects European standards and practices described in [33]. During the intermittent heating phase of a building, the thermal balance equation must include not only the heating of indoor air but also the heat stored by the building's structural elements, especially walls with high thermal mass, which absorb a significant portion of the supplied energy. As described in the ASHRAE handbook – fundamentals, this cumulative heat is represented as an additional component in the heating equation, significantly impacting the accurate assessment of energy demand during the initial phase of system operation [34].

2.5. Analytical model of indoor temperature

Understanding the dynamic response of indoor temperature in buildings hinges on the balance between heating capacity and thermal losses, which can be represented through differential equations. In temporary heating systems, the indoor temperature (t_b) of a building can be modeled by a first-order differential equation that describes the change in temperature over time, depending on the total applied heating power. This model is based on the heat required for permanent heating ($\dot{Q}_n$, in W), the heat accumulation in the air ($\dot{Q}_{Aa}$) and in the walls ($\dot{Q}_{Am}$), as well as the thermal characteristics of the building [35], [36].

$$\dot{Q}_{tot} = \dot{Q}_n + \dot{Q}_{Aa} + \dot{Q}_{Am} = \dot{Q}_n + C_a \frac{dt_b}{d\tau} + C_m \frac{dt_m}{d\tau} \quad (6)$$

Where C_a and C_m– thermal capacity of air and wall (J/K), t_m – wall temperature (°C), and τ - time (s).

This equation describes the temperature behavior and has been widely used in building energy simulations [37], [38]. The model enables the prediction of indoor thermal behavior under varying time conditions and serves as a basis for developing effective energy management strategies. In the case where the outdoor temperature and heating power are constant, the analytical solution of (6) for the indoor temperature, using Laplace transforms, is given in (7) [36].

$$t_b = \left(\frac{\dot{Q}_{tot} + K_{mj} - \dot{Q}_C}{K_{mb}}\right)\left(1 - e^{-\tau/T}\right) + t_0 e^{-\tau/T} \quad (7)$$

Where: t_0 – initial temperature in the building (°C), t_b – the desired or standard internal temperature in a building (°C), K_{mb} – heat transfer capacity of internal walls (W/K), K_{mj} – heat transfer capacity of external walls (W/K), $\dot{Q}_C$ - Constant thermal losses due to ventilation and through windows and interior walls (W); T – time constant (s). This solution shows that the indoor temperature evolves from the initial state toward a steady-state condition with a characteristic time constant, representing the building's thermal inertia [35], [37]. More advanced methods for modeling and analytical solutions involve the use of Laplace transforms and state-space models, which allow the treatment of intermittent heating scenarios, variable conditions, and automatic control [36], [39]. For example, Lü *et al.* [40] present an analytical method for simulating heat transfer in buildings by applying the Laplace transform and Fourier series solutions. For short-term simulations and control management, grey-box models offer a balanced solution between accuracy and complexity. Hossain *et al.* [41] introduce the use of Bayesian neural networks on top of grey-box models, enabling the identification of thermal parameters in real buildings with minimal data. The development of state-space models from physical thermal models is presented by Ghiaus and Ahmad [42], who build modular approaches for building elements such as walls, floors, and ceilings. Their models are formulated in a way that is applicable for optimal control and dynamic analysis. A practical example of the application of the Laplace transform in radiators and wall components can be found in Mižáková and Pitel [43] developed thermal transfer functions that describe the thermal relationships between components. For reduced-order modeling, Ramallo-González *et al.* [44] propose the use of lumped-parameter approaches, which represent the wall as a series of thermal capacitances and resistances, making the model suitable for rapid analyses with possible Laplace-based solutions.

2.5.1. Integration of solar energy

Kosovo has considerable potential for solar energy utilization throughout the year, including the winter period. The average global horizontal irradiation reaches approximately 1351 kWh/m²/year, corresponding to a daily average of around 3.7 kWh/m² [45]. However, during the winter months, irradiation drops to a range of 1.0 to 1.5 kWh/m²/day due to climatic conditions and shorter daylight hours [46]. Optimizing the tilt angle of solar thermal collectors to around 25° enhances solar energy absorption during winter and increases the efficiency of solar heating systems [47], [48]. Under optimal conditions, the contribution of solar energy for space heating in Kosovo during winter is expected to cover between 80% and 100% of the daily demand, with the possibility of maintaining thermal comfort during sunless hours thanks to thermal storage systems [47]. This technology holds significant potential for further development and wide-scale application in Kosovo, especially in the current context of rising fossil fuel prices and the global shift towards renewable energy sources [45]-[48].

Studies by Ramos *et al.* [49] have shown that hybrid systems, which combine solar thermal panels with electric boilers, can reduce electricity consumption for heating by up to 25% during the winter period. This is achieved by using solar energy to heat water, which then supplies the central heating system. This approach to utilizing renewable energy reduces dependence on electric boilers functioning as the primary energy source. In their study, Ma *et al.* [50] examined the feasibility of seasonal solar thermal energy storage in residential buildings in the cold climate of the United Kingdom. Using a system with solar collectors and an integrated thermal storage tank, they analyzed performance under typical climatic conditions. The results indicated that, under optimal conditions and with an installed collector area of approximately 40–50 m², solar systems could cover a significant portion of the annual heating demand. This potential is particularly relevant for regions like Kosovo, where the intensity of winter solar irradiation is sufficient to contribute meaningfully to the energy efficiency of buildings. In the study by Al-Smairan *et al.* [51], a techno-economic assessment was presented for a hybrid system combining an electric boiler with a solar heating/cooling system. They developed an optimization model using a cost and emissions analysis algorithm to determine the ideal activation time of the electric boiler in accordance with solar generation. The results demonstrated a reduction in operational costs and CO_2 emissions of up to 53% per year [51]. These findings clearly show that optimizing the timing of electric boiler operation can significantly reduce emissions and expenses, thereby enhancing the integration of solar energy into hybrid systems. In the local context, Bylykbashi and Hoxha [45] have assessed the solar energy potential in Kosovo and suggested the use of hybrid heating systems as one of the most suitable approaches for improving energy efficiency and reducing dependence on electricity imports, especially during the winter season. On the other hand, Qerimi *et al.* [46] proposed maintenance techniques and design strategies to maximize solar energy collection and ensure continuous cooperation with the electric boiler during periods of low solar radiation.

3. RESULTS AND DISCUSSION

Considering the relevant norms, standards, and thermal recommendations for building thermal energy, this study analyzes a two-story house in Kosovo as a case study. The amount of heat required for heating with an electric boiler (covering thermal losses through the enclosing walls and ventilation) is calculated to be 20 kW. The design outdoor temperature for winter is –18 °C. The building is designed with walls incorporating an external thermal insulation layer, while for comparative thermal analysis and simulations, four additional cases were considered based on the arrangement of wall layers. The thermophysical properties of the wall materials are as follows: For the block layer: thickness δ = 0.25 m, thermal conductivity λ = 0.47 W/(mK), specific heat capacity c = 870 J/(kgK), and density ρ = 1150 kg/m^3. For the insulation layer: thickness δ = 0.18 m, thermal conductivity λ = 0.06 W/(mK), specific heat capacity c = 1460 J/(kgK), and density ρ = 30 kg/m^3. The heat convection coefficients are for the interior α_b = 8 W/(m^{2}K) and for the exterior α_j = 25 W/(m^{2}K).

The analyses and simulations for the four categorized wall layer configurations have highlighted their thermal effects in terms of both heat transfer losses and thermal accumulation. To evaluate the heating system activation time (for achieving the fastest possible heating of the building), the thermal capacity rate of the heating system was considered with values of 20, 21, 22, and 23 kW, assuming an initial indoor air temperature of t_0 = 10 °C. The categorization and ordering of the wall layers were analyzed and simulated only for the external walls, as thermal insulation layers are typically applied on the exterior side of the enclosing walls. Based on the simulations for the four cases with different placements of the building's wall layers, Table 1 presents several characteristic data that can be related to the sizing and arrangement of the wall layers as well as the heating system capacity. The table includes the heating system shut-off time during which the temperature decreases from 20 °C to 15 °C, the overall heat transfer coefficient, the rate of heat transfer through the walls, the amount of heat accumulated in the walls, the time constant, and the heat inertia coefficient of the walls.

From Table 1, it is observed that the temperature drops from 20 °C to 15 °C (after the heating system is turned off) occurs fastest for the wall with internal insulation (in 0.205 hours). In contrast, this shut-off time is longest for the wall with external insulation (8.803 hours). Although the overall heat transfer coefficient, the rate of heat transfer through the wall, and the inertia coefficient are the same, the amount of heat accumulated in the wall with external insulation is significantly greater—about 65 times higher—compared to the wall with internal insulation. This also implies a much larger time constant for the wall with external insulation, approximately 42 times greater than that of the wall with internal insulation. Table 1 clearly shows that walls with external insulation accumulate more heat than all the other cases.

For heating system capacities of 20, 21... 23 kW and an outdoor temperature of –18 °C (in the case of walls without thermal insulation), the amount of heat accumulated at the initial moment (τ = 0) is presented for the indoor air in Figure 1, and for the building walls in Figure 2. The energy accumulated in both the wall and the air is initially at its maximum and gradually decreases during the heating process until it reaches zero. From the comparison of values (from Figures 1 and 2 as well as Table 2), the amount of heat accumulated in the walls is significantly greater than that in the air. For heating system capacities ranging from 20 to 23 kW, the share of accumulated heat is between 0.316% and 0.538% for air, whereas for walls it ranges from 14.056% to 23.929%

Table 1. Four cases of different types of building walls with some thermophysical characteristics

Wall	Turn-off time (h)	Overall heat transfer coefficient (W/m^{2}K)	Rate of heat transfer (W/m^2)	Accumulated heat (J/m^2)	Time constant (s)	Coefficient of inertia (/)
Without IN	3.652	0.926	35.189	$1.626 \cdot 10^6$	$2.078 \cdot 10^5$	5.357
With INI	0.205	0.27	10.27	$6.219 \cdot 10^4$	$1.165 \cdot 10^4$	4.427
With INE	8.803	0.27	10.27	$4.02 \cdot 10^6$	$5.007 \cdot 10^5$	4.427
With IND	2.254	0.149	5.674	$2.981 \cdot 10^5$	$1.282 \cdot 10^5$	5.741

Where IN – insulation, INI – internal insulation, INE – external insulation, IND – double insulation.

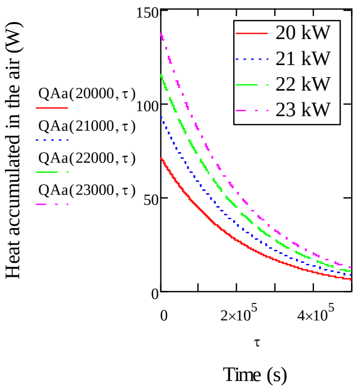


Figure 1. The rate of heat accumulation in the air

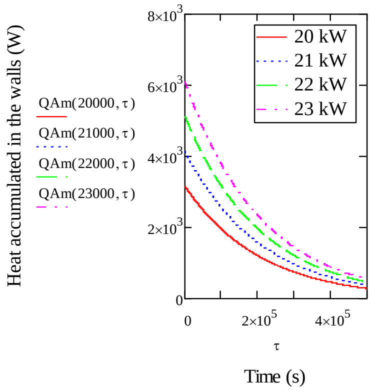


Figure 2. The rate of heat accumulation in the wall

The activation time and the heat loads affecting the capacity of the heating system are presented in the following tables: Table 2 for the wall without thermal insulation (43 cm thick block); Table 3 for the wall with external thermal insulation (25 cm thick block and 8 cm insulation); Table 4 for the wall with internal thermal insulation (18 cm insulation and 25 cm block); and Table 5 for the wall with double-layer thermal insulation (18 cm insulation, 25 cm block, and 18 cm insulation).

By comparing the tables, the values of the specified parameters highlight the importance of the wall layer configuration and its impact on the heating system capacity, energy savings, heating speed, and human thermal comfort. The wall with external insulation shows a lower proportion of energy accumulated in the indoor air (by 0.223%) and a higher proportion in the wall itself (by 24.24%). In contrast, for the wall with internal insulation, the air absorbs approximately 10% of the heat, while the wall absorbs about 15%. In walls without insulation, heat transfer is high, delaying heating and increasing energy use, which reduces thermal comfort. There is also a risk of moisture condensation. The results highlight the need to consider heat accumulation and insulation layers, including interior walls adjacent to unheated spaces. The use of internally insulated walls (data from Table 4) has the advantage of low heat accumulation in the wall, faster room heating, and thermal energy savings. However, it also presents the disadvantage of increased risk of condensation on wall surfaces and rapid indoor cooling after the heating system is turned off. The wall with double-layer insulation (Table 5) significantly reduces heat losses. It contributes to faster achievement of the desired indoor temperature, better retention of heat and temperature within the building, and effective prevention of moisture condensation.

Table 2. Heat loads affecting the heating system capacity – wall without thermal insulation

Heating system capacity (kW)	Turn-on time (day)	Heat accumulated in the air (W)	Heat accumulated in the walls (W)	Contribution of heat accumulated in the air (%)	Contribution of heat accumulated in the walls (%)	Required heat (%)
20	2.554	70.942	3155	0.316	14.056	85.628
21	1.664	92.932	4133	0.396	17.628	81.976
22	1.244	114.923	5111	0.47	20.907	78.622
23	0.996	136.914	6089	0.538	23.929	75.533

Table 3. Heat loads affecting the heating system capacity – wall with external thermal insulation

Heating system capacity (kW)	Turn-on time (day)	Heat accumulated in the air (W)	Heat accumulated in the walls (W)	Contribution of heat accumulated in the air (%)	Contribution of heat accumulated in the walls (%)	Required heat (%)
20	6.155	29.437	3197	0.131	14.241	85.628
21	4.011	38.561	4187	0.164	17.860	81.976
22	2.998	47.686	5178	0.195	21.183	78.622
23	2.399	56.811	6169	0.223	24.244	75.533

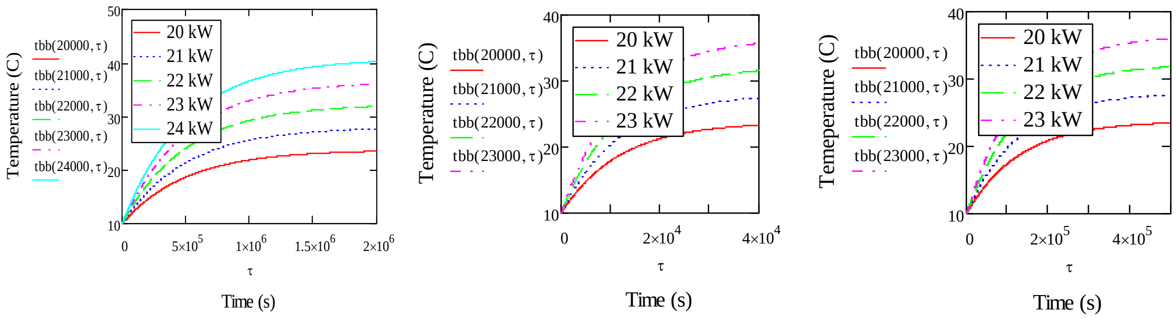
Table 4. Heat loads affecting the heating system capacity – wall with internal thermal insulation

Heating system capacity (kW)	Turn-on time (day)	Heat accumulated in the air (W)	Heat accumulated in the walls (W)	Contribution of heat accumulated in the air (%)	Contribution of heat accumulated in the walls (%)	Required heat (%)
20	0.143	1266	1960	5.638	8.734	85.628
21	0.093	1658	2568	7.071	10.953	81.976
22	0.070	2050	3176	8.387	12.991	78.622
23	0.056	2443	3783	9.599	14.869	75.533

Table 5. Heat loads affecting the heating system capacity – wall with double-layer thermal insulation

Heating system capacity (kW)	Turn-on time (day)	Heat accumulated in the air (W)	Heat accumulated in the walls (W)	Contribution of heat accumulated in the air (%)	Contribution of heat accumulated in the walls (%)	Required heat (%)
20	1.576	114.949	3111	0.512	13.86	85.628
21	1.027	150.581	4075	0.642	17.382	81.976
22	0.768	186.214	5040	0.762	20.616	78.622
23	0.614	221.846	6004	0.872	23.596	75.533

Figure 3 illustrates the significance of (7), which expresses the change of indoor temperature as a function of time, the thermophysical properties of the walls, and the capacity of the heating system. The equation can be adapted to any building model by incorporating additional thermal and climatic parameters. From Figure 3 (as well as from Table 1, which presents the accumulated heat, time constant, and inertia coefficient), it is evident that the steady-state temperature is reached the latest in the case of the wall with external insulation (≈ 2×10^6 s), and the earliest in the case of the wall with internal insulation (≈ 4×10^4 s), while the wall with double insulation exhibits an intermediate value (≈ 4×10^5 s). The selection of the wall type inherently determines the optimal activation time of the heating system required to reach the desired indoor temperature. As previously mentioned, Kosovo possesses the capacity to successfully integrate solar energy into hybrid heating systems, both to compensate for the heat accumulated in the building's walls and to reduce the time required to reach the desired indoor temperature. In the designed case study, under winter conditions and for a building with external thermal insulation, solar energy was utilized to enhance the heating system capacity with a 25% contribution. An electric boiler was integrated with a solar collector system (with an area of approximately 27 m² and a thermal output of around 5 kW) and a thermal storage tank with a capacity of 1500 liters. From an economic perspective, the role of solar energy is significant, as automation enables its use to maintain the minimum or desired indoor temperature even during non-operational hours. On long and sunny days, solar energy contributes as a primary energy source within the electric boiler system, making energy savings indisputable.



(a) (b) (c)

Figure 3. Indoor temperature change for cases: (a) wall with external insulation, (b) wall with internal insulation, and (c) wall with double insulation

4. CONCLUSION

The study conducted an analysis of the impact of thermal insulation layer categorization on the capacity of thermal heating systems for intermittently heated spaces—a challenge commonly encountered in Kosovo. The focus was on identifying the key factors that determine the optimal activation time of the heating system in order to reach the desired indoor temperature as quickly as possible. The research findings revealed that continuous and intermittent heating differ significantly in terms of design approach, operating strategy, system capacity, energy usage, and the thermal insulation characteristics of walls.

Simulations indicate that, in the case study, 10–25% of the heat supplied by the heating system is absorbed by the building walls until a stable indoor temperature and steady-state heat flux through the walls are achieved. For similar buildings with different insulation conditions (based on simulations as well as ASHRAE and EN 12831 standards), the thermal capacity of a system intended for temporary heating typically needs to be 20–50% higher compared to that of a permanent heating system. The objective and approach of the study focused on achieving rapid heating and maximizing energy savings in the building. In the case study, for the designed building with external thermal insulation, solar energy was integrated as an additional energy source (contributing 25%) into the electric boiler system in order to reach the desired indoor temperature in the shortest possible time.

The study's findings showed that rapid heating of the building (even with 20 kW) can be achieved with internal wall insulation, while the integration of solar energy primarily contributes to electricity savings. Walls insulated only internally may face risks of moisture condensation or require a waterproofing layer. Furthermore, the study emphasizes the important role of double insulation (both internal and external), which is considered the most suitable option since it can be used for buildings with both short-term and long-term occupancy. This configuration enables the indoor temperature to be reached quickly and maintained for a certain period after the heating system is turned off. Such walls help achieve optimal thermal performance, prove more economical, slow down heat transfer and heat accumulation, provide continuous comfort, and offer complete protection of the building structure, thereby reducing heating energy consumption. However, considering the practical difficulties related to the installation of furniture (shelves, cabinets, and sofas), electrical outlets, internet and TV networks, and water pipes, it is recommended that double thermal insulation be designed only for rooms with permanent occupancy and not for all building spaces. Additional solar energy can then contribute between 20% and 50%.

The research indicates that the role of solar energy is not only technically viable but also strategically essential for long-term savings, pollution reduction, and energy independence. In our case study, solar thermal collectors together with a thermal storage tank have been integrated into the electric boiler system. The coordinated and dynamic interaction of these three elements, managed through automatic control, provides an efficient, flexible, and economical solution. The system operates using the solar collectors for heating when sunlight is available, and the stored heat in the tank can be utilized as needed. The electric boiler activates only when the collectors and storage tank cannot meet the heating demand. Intelligent control ensures that the most economical energy source is prioritized, while the more expensive source (electricity) serves only as backup. It is expected that the solar energy share of the system will contribute around 25% during winter and subsequently increase, becoming the primary source and thus significantly reducing electricity consumption.

Further investigations in the field of energy savings from hybrid building heating systems could focus on integrating electric boilers with solar collectors and thermal storage tanks, supplemented by devices such as heat pumps (to improve efficiency during low-sun periods), photovoltaic panels, and electric batteries. Research prospects related to thermal comfort and indoor temperature dynamics could be advanced by utilizing (7), which can be adapted to any heating system model and analyses of the thermal demands of the building envelope components.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Rexhep Selimaj	✓	✓	✓	✓	✓	✓		✓	✓	✓				✓
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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors state there is no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

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