Analysis of Multiple Factors Affecting Degree Days

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Abstract : - Degree-days play a crucial role in predicting thermal energy consumption for energy management and forecasting in buildings. Base temperature, commonly used in degree-day calculations, represents the outdoor temperature threshold at which a building's internal heat balance shifts from passive maintenance to active heating or cooling. This study examines key factors influencing base temperature selection through case studies, refining degree-day calculations for greater accuracy. By utilizing advanced modelling tools such as *Degree Days.net* and *Renewables. ninja*. Different countries follow various base temperature conventions, such as 18°C in the USA, 15.5°C in the UK, and 12°C in Switzerland. Unlike a fixed national standard, the true base temperature of a specific building is dynamic, depending on several factors, including the building's thermal properties, the heating system's set temperature, internal heat gains, and solar energy contributions, etc. This work analyses these factors using specific case studies to determine how to calculate the appropriate base temperature for a building. With tools like Degree Days.net, degree-days can be calculated for any desired base temperature. Selecting the most suitable base temperature for each building and heating method ensures more accurate energy predictions.

Key-Words: - Degree days, basic heating temperature, buildings, continuous heating, Intermittent heating, Isolation, mode of heating.

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1 Introduction

There are several ways to calculate heating degree-days (HDD), depending on the available outdoor temperature data. In many engineering practices, in order to make a correct and fast assessment of energy demand within the building control volume, HDDs are employed using both the drops of the outside temperature below a certain base level for a certain time. But in different climate regions, the base temperatures vary, so the concise value can differ due to local regulations. In other words, HDDs are a tool that allows engineers to carry out the energy required to ensure an adequate level of the microclimate conditions that guarantee the comfort level (body and mind are equally satisfied) within the building's environment when temperatures are reduced. In real life, architects, engineers, and energy managers call HDD to evaluate the required amount of energy for space heating purposes [1] and a simple and fast way to enable the optimization of building performance, [2]**.** The weather is one of the main factors to consider when designing a building because it represents the most important boundary condition to affect the dynamic behaviour of the building, [1]. By analyzing HDD, designers and energy planners can estimate the heating energy required based on outdoor temperature variations [3], helping to improve efficiency and reduce energy costs, as given for the case of Korca, suggestions of the most used heating systems, [4]. Models that predict heating and cooling degree-hour indexes for residential buildings by considering changes in outdoor air temperature are given in the study, [5]. Prediction of energy demand for heating of residential buildings using variable degree day [6], where Degree day curves were created for Debrecen (Hungary), for the period 1964-2012, showing that the variation of degree day by decades is between 15 and 18%. The study [7] determined the base temperature for 60 cities in India using the Energy Signature and Performance line method.. Furthermore, the U.S. Department of Energy (US-DOE) developed sixteen reference buildings, which have been used for eight climate zones of India, exclusively classified using the methodology of ASHRAE Standard 169–2013 on weather data of Indian cities. In the study [7], it was observed that the cooling base temperature varies from 6.8 °C to 28.6 °C for the large hotel and 8.7–28.1 °C for office buildings, while the heating base temperature ranges from 13.8 °C to 21.4 °C for the large hotel and 10.4–18.7 °C respectively for different cities. In fact, from the recent literature review, different countries and regions may and can adopt standardized base temperatures based on regulatory guidelines, climatic conditions, and historical data, easily adaptable to reflect the specific characteristics of a building and its operational requirements. Furthermore, the balance of the point temperature and heating degree-days in different climate conditions for building energy efficiency applications is given in the study [8], where a calculation method of balance point temperature and heating degree-days is proposed, and the research concludes that a 1°C rise in outdoor climate results in a 0.28°C increase in balance point temperature. In the study of [9], highlighting the fact that the marine climate doesn't seem to affect the heating needs of the island buildings, we looked at. Improving insulation by 60% can lower the balance temperature by about 4.5°C, based on degree-hour and degree-day analyses in the coastal Mediterranean cities of Patras and Kalamata, Greece. In these cities, urban areas experienced 19–24% fewer heating degree-hours compared to rural areas, while cooling degree-hours were 9–22% higher in the city than in the countryside, [9]. In the study performed by authors in [10], energy consumption patterns in relation to heating and cooling degree days across the urban landscape of Athens, Greece is investigated, aiming to deliver a precise and location-specific assessment of temperature-driven energy demand variations within the Greater Athens Area (GAA). In this regard an exact and correct computation of HDD is very important in everyday engineering applications, that allow planners to better assess the energy demand in the future, leading to design a more precise heating system, and contributing to the development of smart and well oriented energy efficiency policies [11], [12], furthermore, an aggregated analysis of electricity consumption used for space heating absolutely gives a clear picture of the electricity variation on time. Using reliable and correct base temperatures, energy planners bring to a more realistic energy forecasts as the need for energy going for space heating demand and system efficiency is a weather impacted quantity. Digital tools and climate databases further refine HDD calculations, helping professionals make well-informed decisions for both residential and other commercial projects. The study conducted by the authors in reference [13] examines the impact of modifying the heating degree day calculation method on building recommendations in Chile's thermal building codes to maintain consistent heat transmission losses through the building envelope, while accounting for diverse geographical regions and climatic conditions. An analysis of data provided from 165 meteorological stations reveals significant differences in the geographical distribution of HDD values calculated using the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and United Kingdom Met Office (UKMO) methods, particularly in desert regions. In contrast, both methods produce similar HDD values, [14]. Degree-days represent the cumulative difference between a reference outdoor temperature and the average daily outdoor temperature over a specified period. HDD can be used in many sectors, such as agriculture, residential, and city planning, to estimate heating demand, and can be calculated using Equation 1.

$$HDD = \sum_{i=1}^{n} \left(t_{jr} - t_{jm} \right) \tag{1}$$

where: t_{jr} - stands for the reference outdoor temperature (the base temperature),
t_{jm} - stands for the average daily outdoor temperature for heating.

This concept is widely used in architecture, engineering, and energy management to assess heating demand [15] and optimize building performance, [16]. By analyzing HDD, designers and energy planners can estimate the heating energy required based on outdoor temperature variations [17], helping to improve efficiency and reduce energy costs. Predictive models for heating and cooling degree-hour indexes in residential buildings, accounting for outdoor temperature changes, are presented in the study, [18]. Prediction of energy demand for heating of residential buildings using variable degree day [6], where Degree day curves for Debrecen (Hungary), for the period 1964-2012, showing that the variation of degree day by decades is between 15 and 18%, were created. In the study

[19], it was observed that the cooling base temperature fluctuates from 6.8 °C to 28.6 °C for the large hotel and 8.7–28.1 °C for office buildings, while the heating base temperature ranges from 13.8 °C to 21.4 °C for the large hotel and 10.4–18.7 °C respectively for different cities. Furthermore, the balance of the point temperature and heating degree-days in different climate conditions for building energy efficiency applications is given carefully in the study [20], where a calculation method of balance point temperature and heating degree-days is proposed. Moreover, the research concludes that a 1°C rise in outdoor climate results in a 0.28°C increase in balance point temperature. Accurate computation of HDD is fundamental for diverse applications, including energy demand forecasting [21], the optimization of heating system design, and the development of data-driven energy efficiency policies, [22], [23], [24]. The study examines three different heating systems applied to three building categories, considering scenarios for the case of poor insulation and the absence of energy management strategies. This comprehensive approach highlights the effectiveness of the methodology in assessing real-world energy performance for varying conditions achieving optimization of the heating demand through a specific technology that can be used.

2 Variation in HDD Base Temperatures Across Countries

Fluctuations in heating degree-day, maintaining a base temperature, significantly impact energy policies and building design strategies. Building energy model validation and estimation and cooling degree days (HDD–CDD) based on accurate base temperature, [25]. The most recent studies assessed in the previous section have proven that while the absolute decrease in HDDs is stronger than the increase in cooling degree-days (CDDs), the relative percentage increase in CDDs is higher than that of HDDs. The most substantial absolute decreases in HDDs are expected during February and March, whereas the highest absolute increases in CDDs occur during the summer months. Countries with higher HDD values tend to enforce stricter building regulations, codes and rules, advanced insulation standards, and higher heating efficiency targets. In contrast, regions with lower energy needs (with lower HDDs) tend to address energy and climate issues by employing passive heating strategies, adaptive insulation, and hybrid energy systems to meet the nearly zero energy building agenda (nZEB). As climate change shifts temperature patterns, it requires urgent standardization of heating degree-day calculations to calibrate energy efficiency strategies on a global level. This approach can help in minimizing heating energy needs, cut carbon emissions, and make buildings more resilient. An evaluation was carried out to understand how the base temperature for heating degree-days depends on multiple factors in building energy predictions, [26]. Analyzing multiple factors influencing base temperature selection for HDD calculations proved that accurately estimating the optimal base temperature is essential for improving heating demand predictions. This research examined the relationships between annual HDD (based on 15.5°C), building location, and mean daily solar insolation. The results showed that both annual heating degree-days (HDD) and solar radiation have a strong influence on the choice of base temperature, while base temperature also appears to be related to the building's location. Additionally, a city-scale [27] degree-day method was applied in Strasbourg Eurometropolis, France, to estimate space heating energy demand. Sensitivity analysis indicates that heating energy demand is strongly influenced by building insulation and thermostat settings [28], however, changes in building energy properties have little impact on the urban heat island (UHI) effect, [29]. HDD base temperatures vary across countries, depending on local climate history and building performance, [30]. In Northern Europe - such as Sweden, Finland, and Norway - base temperatures of 17–20 °C are commonly used to account for the long and severe winters typically maintained for comfort issues. In Central and Southern Europe (for example in Germany, France, and Italy), base temperatures typically range from 15°C to 20°C, depending on local climate conditions. In the UK, two specific base temperatures are commonly used:15.5°C and 18.5°C. In North America, the standard base temperature is 18.3°C (65°F). A summary of standardized base temperatures across these countries, in both continents (USA and EU) is shown in Table 1 (Appendix).

Based on this idea and Albania's climate features and fluctuations from Mediterranean along the coast to continental in the mountainous regions, fixed reference temperatures in HDD calculations are less reliable. Winters in western countries are relatively mild, whereas the eastern and northern countries face much colder conditions. Variations in space heating demand per square meter are higher for a reference building.

2.1 Dynamic Factors Influencing Core Reference Temperature in HDD Calculations

As is widely known, the reference temperature in heating degree-day calculations is not a fixed value, but a dynamic parameter shaped by multiple factors, including building insulation, heating system efficiency, internal and solar heat gains, climatic conditions, occupant behaviour, and heating control strategies. a simple dynamic model to simulate heating and cooling energy consumption in buildings. The model consists of several transient energy balance equations for the external walls and the internal air, based on a lumped-capacitance approach, and it has been implemented on the Matlab/Simulink® platform, [31]. Engineering is all about problem-solving, scientific and mathematical reasoning, and thinking in systems. Engineers and researchers work to find ways to improve energy efficiency, manage risks, and innovate building designs with new practices - all while keeping safety and sustainability in mind. By using this approach, HDD methods can be further improved and converting them to more flexible in solving future energy and climate issues. In Albania, no effort has been made, and these factors are largely ignored in terms of how they impact the energy forecast and transition in the building sector. Weather plays a crucial role in building design, as it sets the conditions that heavily influence a building's thermal performance and energy consumption. Properly accounting for these variables is essential for optimizing energy efficiency and promoting sustainable building practices, [1]. Considering these factors leads to a more precise energy modelling and policymaking with improved heating efficiency using the heating degree-day (HDD) method as a powerful tool for anticipating a national climate or annual heating demand for a heating period, [3]. Anyway, the future energy needs should move away from relying on predefined values to using flexible and variable data employing data-driven methods. In Table 2 (Appendix) main parameters affecting the core reference temperature and thermostat setpoint based on thermo-physical properties of the building materials, heating system, and operation management are included, giving a strict description and impact on the factors. Table 2 (Appendix) lists the main factors that determine the building's reference temperature, which is very important in achieving comfort and energy efficiency goals. From a thermodynamic point of view, materials, the insulation type, and thermal mass impact the way heat is absorbed, stored, and released. On the other hand, external factors such as weather parameters, coupled with internal heat gains from occupants and appliances within the building environment, further impact the indoor temperatures. Well-designed and structured HVAC systems, a proper ventilation system, and smart building orientation and integration of building energy management are ways to levelize comfort for the entire heating period. Heating methods impact thermostat settings differently. Forced air and electric systems require frequent or higher adjustments, while radiant, boiler, and geothermal heating provide steady warmth, allowing for lower, more stable set points, as can be seen in Table 3 (Appendix).

3 Computational Model: Mathematical Formulation Of Heating Demand In Quasi-Steady-State Mode

A comprehensive mathematical model was developed to analyze the factors influencing heating capacity. It accounts for two operational scenarios with different thermal conditions and heat transfer behaviours, allowing for accurate assessment of heating performance across various building types, usage patterns, and both continuous and intermittent system operation.

3.1 Heating Capacity in Steady-State Heat Transfer Mode (Continuous Heating)

This regime, given as a steady state heat transfer mode, considers a thermally stabilized environment, where the rate of heat input exactly balances the rate of heat loss, creating a state of thermal equilibrium. In this scenario, the system operates by keeping a constant temperature value over time. So heat transfer in this regime occurs steadily and continuously. From the heat transfer theory, specifically the classical steady-state heat transfer principles, three ways of heat transfer, such as conduction, convection, and radiation, combine their effects to maintain thermal equilibrium conditions. The main equations include Fourier's Law for steady-state conduction (assuming no internal heat generation, as described by the Laplace), Newton's law of cooling for convection, and the Stefan-Boltzmann law for radiation, presented in Equations 1, 2, and 3.

$$\frac{\partial t}{\partial \tau} = \alpha \cdot \nabla^2 t + \frac{q_v}{k} \quad (2)$$

$$Q = hA(t_s - t_{out}) \quad (3)$$

$$Q_{rad} = \varepsilon\sigma A({t_s}^4 - {t_{out}}^4) \quad (4)$$

$\frac{\partial t}{\partial \tau}$ = Temperature gradient, $\nabla^2 t$ Laplace operator, k- thermal conductivity (W/mK) and q_v - volume heat generation (W/m^3). The type of heating system, such as using indoor emitters (radiators, underfloor heating, convectors, etc.), is influenced by the heat delivered to the space to maintain the comfort level.

$\alpha = {k}/{\rho} \cdot c_p$ stands for thermal diffusivity (m^2/s)

k stands for thermal conductivity of the material (W/mK)

h stands for convection heat transfer coefficient (W/m^{2}K)

Q_{rad} stands for radiative heat transfer rate (W)

ε stands for emissivity coefficient (dimensionless, $0 \leq \varepsilon \leq 1$)

σ stands for Stefan-Boltzmann constant (5.670×10^{-8} W/m^{2}K)

A = Surface area (m²)

3.2 Heating Capacity in Intermittent Heating (Transient Heat Transfer)

In comparison to the steady-state scenario, the transient regime has on-off heating cycles, which means that heat flux is not constant but varies over time. As a result, the temperature value changes, too, as defined by Fourier's law, considering thermal inertia, heat storage, and the heat fluctuations through materials as a function of time. In this scenario, temperature evolution requires solving transient heat conduction equations, such as the heat diffusion equation, with appropriate initial and boundary conditions. By examining both heat transfer regimes, the unsteady scenario provides a more accurate evaluation of thermal stability and system performance. Comparing these scenarios also helps us understand how different operational modes affect system behaviour and supports the design of optimized heating strategies in engineering and industrial applications.

3.3 Governing Equations in the Case of Continuous Heating

In the quasi-steady-state heat transfer mode, heating capacity is calculated assuming continuous operation and a uniform thermal inertia that guarantees the indoor temperatures unchangeable over time without the need for complex dynamic simulations. In this scenario, a gain utilization factor is used to consider internal and solar heat gains, a quantity that impacts the decrease in heating needs and parameter furthermore helping to avoid overestimating passive heat gains. In this case, the model considers heat losses, internal gains, and solar contributions to identify optimal heating solutions. In addition to that, combining building properties with heat emitter characteristics gives insight to designers to further improve energy efficiency, maintain the desired comfort level, and select the right heating systems. This approach does not need a complex equation to handle, but by performing a simple and practical mathematical model.

$$Q_t = \left[F_{1cu} \cdot \sum_{i=1}^{n}(AU) + F_{2cu} \cdot C_v\right] \cdot (t_{op} - t_{out}) \quad (5)$$

In equation 5 Q_t represents the total heat loss (W) [30], F_{1cu} and F_{2cu} empirical correction factors related to the building characteristics and heating system properties; $\sum(AU)$ sum of the thermal transmittance (W/K) over all envelope surfaces, C_v ventilation heat loss coefficient (W/K), t_{op} operating temperature at the centre of the occupied space (°C) and t_{out} is the outdoor air temperature (°C), $\sum A$ represent the total surface area of the heat-transmitting envelope (m²), and R reflects the thermal resistance factor, a measure of the heat retention properties of the building materials. Moreover, both terms F_{1cu} and F_{2cu} are computed by the mathematical expression given in Equations 6 and 7 below, [30].

$$F_{1cu} = \frac{3(C_v + 6\sum A)}{\sum(AU) + 18\sum A + 1.5R(C_v - \sum(AU))} \quad (6)$$

While F_{2cu} can be calculated by using Equation 7, [30].

$$F_{2cu} = \frac{\sum(AU) + 18\sum A}{\sum(AU) + 18\sum A + 1.5R(3C_v - \sum(AU))} \quad (7)$$

In this case, the corresponding indoor air temperature is given by the mathematical expression given in Equation 8

$$t_{st} = \frac{Q_t \cdot (1 - 1.5R) + C_v + 6\sum A t_{op}}{C_v + 6\sum A} \quad (8)$$

where t_{st} represents indoor air temperature, and t_{op} belongs to the operating temperature at the centre of the occupied space (°C).

For radiators, the heat output follows a power-law relationship in Equation 9, [30].

$$Q = k_r A(t_s - t_{op})^n \quad (9)$$

k_r stands for Radiator heat transfer coefficient (W/m²K)
$n = 1.3$ is an empirical exponent for heating radiators

For underfloor heating (UFH), conduction through the flooring material is the only heating transfer mode that dominates the entire process and can be calculated using Equation 10.

$$Q = \frac{k_f A(t_s - t_{op})}{d} \quad (10)$$

k_f stands for thermal conductivity of the floor material (W/m•K)
d stands for floor thickness (m)

To ensure occupant comfort, the operating temperature must fall within an acceptable range systematically designed by considering activity level, building type and category, and climatic regions, too.

$$t_{min} \leq t_{op} \leq t_{max} \quad (11)$$

Additionally, in systems where radiant heating plays a role, the mean radiant temperature t_{mrt} should be factored into the operative temperature calculation:

$$t_{op} = \frac{t_{air} + t_{mrt}}{2} \quad (12)$$

t_{air} = Indoor air temperature (°C)
t_{mrt}= Mean radiant temperature (°C)

3.4 Intermittent Heating

Intermittent heating refers to systems that operate in cycles, turning on and off according to building occupancy or scheduled use. This approach is common in offices, schools, and homes that are not occupied around the clock. Assessing the heating capacity for such systems requires taking into account the challenges of periods when the system is not operating and the need to achieve a rapid temperature value. As a result, intermittent heating is a way to reduce energy consumption, but it requires concise scheduling, especially in unoccupied intervals. Sometimes, to overcome this issue in modern HVAC systems, the version known as setback temperature, as a technical approach to save energy, is widely used.

Despite this, intermittent heating has a notable effect on lowering the heating base temperature- the outdoor temperature below which heating is required- as well as reducing heating degree days (HDD) and overall energy use. Unlike continuous heating, which maintains a constant indoor temperature, intermittent systems allow the indoor temperature to fall during unoccupied periods. This means the system only operates when necessary, effectively lowering the base temperature and, in turn, reducing HDD. Since HDDs are calculated based on the difference between the heating base temperature and outdoor temperature, lowering the base temperature decreases the total number of HDD, indicating less heating demand over time.

For systems that take longer to respond, such as underfloor heating (UFH), these dynamics are particularly important. Considering these factors, intermittent or peak heating loads can be calculated using the mathematical expression provided in Equation 13, [30].

$$Q_p = F_3 \cdot Q_t \quad (13)$$

where F_3 - is a value based on the thermal response factor and the total operating hours of the heating system, including preheating, but neglecting the time for the system to reach its operating conditions, and is given by the mathematical expression in Equation 14, [30].

$$F_3 = \frac{24 \cdot f_r}{t_0 \cdot f_r + (24 - t_0)} \quad (14)$$

where t_0 is the duration of heating system operation (including preheating) (h) and f_r is the thermal response factor and can be calculated using the expression in Equation 15, [30].

$$f_r = \frac{\sum(AY) + C_v}{\sum(AU) + C_v} \tag{15}$$

f_r stands for the thermal response factor

$\sum(AY)$ – belongs to the sum of the products of the building envelope areas with corresponding thermal acceptability ($\frac{W}{K}$).

$\sum(AU)$ – is related to the sum of the products of the envelope areas and the corresponding thermal transmission coefficient for the surfaces through which heat transmission occurs, and C_v represents the heat losses through ventilation ($\frac{W}{K}$). Intermittent heating is a strategy to keep the temperature as per comfort level, while the heating system operates in a fluctuating mode instead of continuously, fully in compliance with the occupancy schedules and thermal response characteristics of the building, including residential, commercial, and institutional ones. With intermittent heating, the effective heating base temperature is lowered because the system allows temperature reductions during unoccupied hours. This leads to a decrease in HDD, reducing total heating demand over time. To accurately assess the energy performance of intermittent heating, a time-dependent heat balance model must be established. The temperature evolution of the indoor air during a setback period is given by the heat loss Equation 16, [30]:

$$\left(\frac{dT_{int}}{dt}\right)_{vol} = \left\{-\frac{Q_{loss}}{C_{th}}\right\} \tag{16}$$

C_{th}= Thermal capacitance of the space (J/K), defined as $C_{th} = \rho V c_p$, where ρ stands for the air density, V shows the room volume, and c_p is the specific heat capacity of air with constant pressure. The solution of the given equation above yields an exponential temperature decay form model, [30].

$$T_{int}(t) = T_{setback} + (T_{init} - T_{setback}) \cdot e^{-\frac{t}{\tau}} \tag{17}$$

T_{init} represents the indoor temperature at the start of the setback period (°C)

$T_{setback}$represents the lowered temperature during setback (°C)

τ is the thermal time constant, defined as τ, representing the building's response rate to temperature change, and can be calculated by the mathematical expression in Equation 18, [30].

$$\tau = \frac{C_{th}}{(AU + C_v)}(h) \tag{18}$$

The reheating power required to restore the indoor temperature within a given time τ_r is derived as given in Equation 19, [30].

$$Q_{reheat} = C_{th}\frac{(T_{setpoint} - T_{setback})}{(\tau_r)}(h) \tag{19}$$

$T_{setpoint}$ - represents the desired temperature after reheating (°C)

τ_r - represents the recovery time (h)

This model helps optimize heating schedules by ensuring setback temperatures are low in a level that have possibility to save energy, while still allowing the building to warm up quickly with minimal effort, largely depending on its thermal mass and insulation. As it is known, buildings with high thermal mass store and release heat slowly, which means they can handle longer setback periods without significant temperature drops. When it's time to reheat, these buildings benefit from a gradual, controlled approach that avoids energy spikes while maintaining comfort. In contrast, buildings with low thermal mass lose heat quickly, so setback periods must be shorter to prevent the drops in space temperature. Hence, striking the right balance between setback diapason and reheating strategy is very important to maximizing energy efficiency for a stable comfort level in occupied hours.

4 Baseline Reference Temperature(S) of a Building, (t_{jr})

The baseline reference temperature t_{jr} The threshold of a building defines the temperature at which heating or cooling activation is necessary to sustain thermal comfort. This temperature varies based on the building's thermal properties, including thermal mass, insulation levels, air infiltration rates, and internal heat gains from occupants and equipment. It serves as a dynamic indicator of a building's ability to retain or lose heat, influencing energy efficiency and system responsiveness. In high thermal mass buildings constructed of concrete, brick, or stone types, heat can be stored and released gradually, stabilizing indoor temperatures. As a result, the t_{jr} remains lower and more stable, allowing for longer setback periods without significant discomfort.

Buildings that have a high thermal mass can allow lower indoor temperatures before heating is needed, which helps reduce overall energy demand and shave the peak load on the national electricity system. The situation is not the same for low thermal mass buildings, often constructed based on lightweight materials like wood or steel, glass, etc., as they cannot store heat effectively. In this case, their indoor temperatures change more quickly, which means that higher setpoints are needed to avoid excessive cooling during the day. The heating system must respond faster, and with shorter but more frequent cycles, to keep the desired level of comfort for the occupants.

As a result, the exact indoor temperature threshold for activating the chosen heating system depends on factors such as the local climate, occupancy behaviour, and ventilation rates, making it essential to think about heating strategies fully in compliance with the characteristics of a given building.

Optimizing the reference temperature according to a building's thermal profile improves energy efficiency by reducing unnecessary heating while maintaining thermal comfort levels, too. To determine the t_{jr} For the above-mentioned cases, we refer to EN ISO 13790 in the diagram in Figure 1 (Appendix), which provides an overview of the calculation procedures outlined in EN ISO 13790 and how they interact with other standards. The diagram likely illustrates a flowchart that simplifies the process of determining a building's energy needs for heating and cooling based on energy balance principles [30]. This structured approach gives designers a clear framework to concisely evaluate energy performance, fine-tune building design, and ensure compliance with regulations in force. As depicted in Figure 1 (Appendix), the energy needed to heat a given control volume (room, house, office, etc.) can be described mathematically in Equation 20. This equation considers heat losses through the building envelope, ventilation losses, internal heat gains, and the contribution of the desired heating system, providing a comprehensive picture of how energy flows within the space of a given building, [30].

$$Q_{en} = Q_{tr} + Q_{ven} - \eta Q_{br} \tag{20}$$

The base temperature for heating is basically the point where a building environment has the desired parameters, in other words, it stands comfortable on its own due to the heat gains from people, lights, and electrical appliances. In short, it represents the case without needing extra energy from the heating system. Q_{en} to balance heat lost to the surrounding environment.

At a steady state condition, the energy balance equation can be rewritten as given in Equation 21, [30].

$$Q_{en} = Q_{tr} + Q_{ven} - \eta Q_{br} = \sum q_{en} = 0 \tag{21}$$

The utilization factor η accounts for the dynamic thermal behaviour of a building, particularly its thermal inertia - the ability of the building's structure to store and release heat, mainly used to refine heating energy calculations by considering how the building responds to fluctuating indoor and outdoor conditions Figure 2 (Appendix). The utilization factor (η) depends on a ratio, denoted as γ regarded as the heat demand to the heat capacity of the building.

By understanding and optimizing thermal inertia, designers and engineers can create energy-efficient heating systems that balance comfort, energy savings, and thermal stability. This indicator represents the ratio of a specific heating-related parameter. Q_{br} to the total heat transfer components in a building, which include ventilation heat losses and transmission heat losses Q_{ven} *and* Q_{tr} respectively and can be calculated by Equation 22, [30].

$$y = \frac{Q_{br}}{Q_{ven} + Q_{tr}} \tag{22}$$

The base temperature for heating is derived from the energy balance of the building and represents the outdoor temperature threshold below which heating is required to maintain indoor thermal comfort and can be determined by transforming Equation 21 then the base temperature for heating. t_{jr} is given from the mathematical expression in Equation 23, [30].

$$t_{jr} = t_{st} - \frac{Q'_{br}}{U_{env} + \frac{C_v}{A}} \tag{23}$$

t_{jr} = Base temperature for heating (°C). The outdoor temperature below which heating is needed to maintain indoor comfort.

t_{st} stands for Setpoint temperature (°C). The desired indoor air temperature for comfort (steady-state indoor temperature).

Q'_{br}represents the effective internal heat gains per unit area (W/m²). Commonly, this represents the heat gains due to occupants, the lighting system, and different electrical appliances

U_{env} represents the average thermal transmittance of the building envelope (W/m²K) of the building envelope, such as walls, windows, roof, and floor.

C_v stands for the ventilation heat loss coefficient (W/K). Represents heat lost due to air exchange between indoor and outdoor spaces.

A represents the total floor area of the building (m²). Used to normalize ventilation losses per unit area**.**

5 Tested Building Categories

This study explores how various factors affect the heating energy demand in buildings that are considered to have the same envelope. Key aspects examined in this study include whether thermal insulation is applied or not, thermostat settings, heating operation modes (continuous versus intermittent), and the type of occupancy, for three building categories: kindergartens, housing, and offices. The study also looks at how different heating systems, such as underfloor heating, radiators, and air-based systems, interact with internal heat gains from people, equipment, and lighting. The deliveries highlight the fact that energy demand can vary as a function of occupancy and the heating approach used. Insulation emerges as a critical factor in reducing energy use, while intermittent heating can provide substantial savings compared to continuous operation, depending on the heating system and the building's internal heat contributions. The key parameters to precisely assess and evaluate the study's goal are outlined in Table 4 (Appendix).

For a consistent building envelope, heating energy demand can vary significantly depending on the occupancy type and heating mode, as suggested, [32].

6 Simulation Results And Discussion

This section presents the simulation results, which show that occupancy, heating method, and insulation all influence the chosen building's category energy use. By adapting heating strategies to how a building is used, energy can be saved while maintaining comfort, guiding more efficient and sustainable heating design. Referring to Equation (11), the temperature set point and basic reference temperature for two distinct heating modes can be determined based on the thermal transmittance (U_{envel}) and heat capacity (C_v) of the building envelope. These parameters play a crucial role in defining the thermal behavior of the building and optimizing heating performance under varying conditions (unsteady operation).

Figure 3 (Appendix) shows how the indoor air temperature varies under different conditions, considering whether the building is insulated and whether the heating runs continuously. The graph highlights how both insulation and the type of heating system strongly affect indoor comfort. Buildings with good insulation generally need less energy to maintain a stable temperature, while from the simulation results, it is noticed that the choice of heating system plays a key role in how efficiently the desired temperature is reached and maintained.

The graph in Figure 4 (Appendix) presents the baseline reference temperature for a building without insulation under continuous heating conditions, plotted against the set point temperature. Variations in heating technologies and building type are consistent for the two cases: the set point temperature and baseline temperature, ranging from 20.97 ºC for kindergarten with UFH, 23.83 ºC for housing heated with radiators, to the maximum value of 26.12 ºC for offices if they are using an air heating system, while the baseline temperature varies across technologies from 20.12ºC, 21.06 ºC and 26.03ºC, respectively.

The graph in Figure 5 (Appendix) illustrates the baseline reference temperature for a building with insulation under continuous heating conditions, plotted against the set point temperature. In comparison to the results without insulation, in this case, the presence of insulation in the chosen building categories leads to a noticeable reduction in the baseline temperature. This decrease in the baseline temperature is due to the effectiveness of thermal insulation that minimizes heat loss through the building envelope. The set point temperature and baseline temperature, ranging from 20.09ºC for kindergarten with UFH heating system, 22.04ºC for housing heated with radiators, to the maximum value of 23.71ºC for offices if they are using an air heating system, while the baseline temperature varies across technologies from 17.07 ºC, 15.9 ºC, and 17.07, respectively ºC. The graph in Figure 6 (Appendix) presents the variations in the baseline reference temperature and indoor air temperature for the chosen building categories with and without insulation under intermittent heating conditions. This graphical representation highlights the strong influence of different heating systems on both the indoor temperature and the baseline temperature values. As we can see baseline reference temperature for the kindergarten varies from 17.07ºC to 20.75ºC, an increased by 21.55% if the building lacks the insulation layer. For the case of housing heated by radiators, the baseline temperature varies from 14.87 ºC to 23.28ºC which is increased by 56.55 % if the building lacks the insulation layer. And the last building group, offices, is the baseline temperature is increased from 16.93 ºC to 26 ºC for an air-heated system due to the lack of the insulation layer, equivalent to 53.57% more energy.

From the simulation results, a strong relationship of baseline temperatures among building categories and HDDs under the case without and with an insulation layer is depicted in the graph in Figure 7 for continuous heating conditions. For example, the kindergarten baseline temperature is reduced from 20.1 ºC to 17.1 ºC (-14.92%), housing from 21.1 to 15.9 ºC (-32.70%), and offices from 26 ºC to 17.1 ºC (-52.04%).

As can be seen from the reduction rates, the presence of an insulation layer on the building envelope reduces the baseline temperature meaningfully, a matter of improved thermal efficiency and reduced energy requirements to meet the indoor comfort. In the graph in Figure 8 (Appendix), the baseline reference temperature and HDD for the case without and with insulation for three different building categories and heating systems are given. The baseline reference temperature is a function of heating system, building category, and insulation level. The higher the insulation level lowers the baseline reference temperature results. In our case study, the insulation level is calculated using data taken from fully in accordance with the Albanian governmental package meeting the minimal energy efficiency criteria in the building stock, [33].

From the graph in Figure 9 (Appendix), the variation in Heating Degree Days (HDD) for both cases, an insulated and not insulated building, is given. The results clearly indicate that insulated buildings experience significantly lower HDD values compared to uninsulated building across with a heating system applied. This difference is highly impacted as the presence of the insulation layer reduces heat loss, thereby decreasing the demand for space heating for a desired indoor comfort level. As a result of all the above simulations performed among building categories and heating systems used, the importance of insulation in improving energy efficiency, reducing energy bills, and environmental impact is also highlighted.

7 Conclusions

The study is extended in three different building categories in Albania, analysing the variation of baseline temperature as a function of heating system type, building category, for the case with and without an insulation layer. The above analyses are carried out for the case of a continuous and intermittent heating regime. As a conclusion, in our study, it is shown that:

1. Thermo-insulated buildings as depicted in Figure 4, Figure 5, Figure 6, Figure 7 and Figure 8 (Appendix), generally have a lower reference base temperature for heating, but this temperature varies depending on whether continuous or intermittent heating is used.
2. Intermittent heating affects thermal losses differently than continuous heating, due to fluctuations and dynamic evolution.
3. The heating method directly influences both the set-point temperature and the reference base temperature, which impacts energy consumption and thermal comfort.
4. From the simulation, it is evident that the reference base temperature should be individually defined across building categories, considering the HDDs.
5. The buildings tested in this study have their specific degree day value as given in the graph in Figure 9 (Appendix).

The insights from this study will be a starting point and will contribute to the development of more sustainable heating system designs in Albania.

8 Future Work

Our future research is expected to use more advanced heating optimization techniques and predictive control algorithms in the management of the building's base reference temperature.

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Declaration of Generative AI and AI-assisted Technologies in the Writing Process

The authors wrote, reviewed, and edited the content as needed and have not utilised artificial intelligence (AI) tools. The authors take full responsibility for the content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

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Conflict of Interest

The authors have no conflicts of interest to declare.

APPENDIX

Table 1. Standardized heating temperatures in different countries (°C), [30]

Country	**Base heating temperature (°C)**
European Union	15.5
Denmark	17
Finland	17
Switzerland	12
United States	18
UK	15.5 18.5

Table 2. Factors affecting the core reference temperature in a building, [30].

Factor	**Description**	**Impact on core temperature**
Building Insulation & Thermal Mass	The level of insulation and material heat storage capacity.	Better insulation reduces heat loss, maintaining a stable temperature.
Heating System Efficiency	Performance of heating systems, including energy efficiency.	A more efficient system maintains desired temperatures with less energy.
Internal Heat Gains	Heat from occupants, appliances, and lighting.	Increases indoor temperature, reducing the need for additional heating.
Solar Heat Gains (SHG)	Sunlight entering through windows and absorbed by surfaces.	Natural heating effect that can reduce reliance on artificial heating.
Weather conditions	Wind, humidity, temperature, and local climate effects.	External cold or heat influences indoor temperature stability.
Occupant Behavior and Preferences	Usage patterns, thermostat settings, and heating habits.	Different preferences can raise or lower the core temperature threshold.
Heating Mode	Type of heating used (radiant, convection, underfloor, etc.).	Different modes distribute heat differently, affecting comfort and efficiency of the supposed system.

Table 3. Heating Method Used and Thermostat Set Point Influence, [30]

Heating System	**Characteristics**	**Impact on Thermostat Set Point**
Radiators/Boilers	Provides quick heat but is less efficient in maintaining a consistent temperature.	Requires higher set points for comfort.
Heat Pumps	Operate efficiently at steady, lower temperatures.	Best with lower, consistent set points.
Underfloor Heating	Distributes heat evenly across large areas.	Works well with lower set points.
Zoned Heating	Allows different temperatures in different rooms.	Set points vary by room and usage.

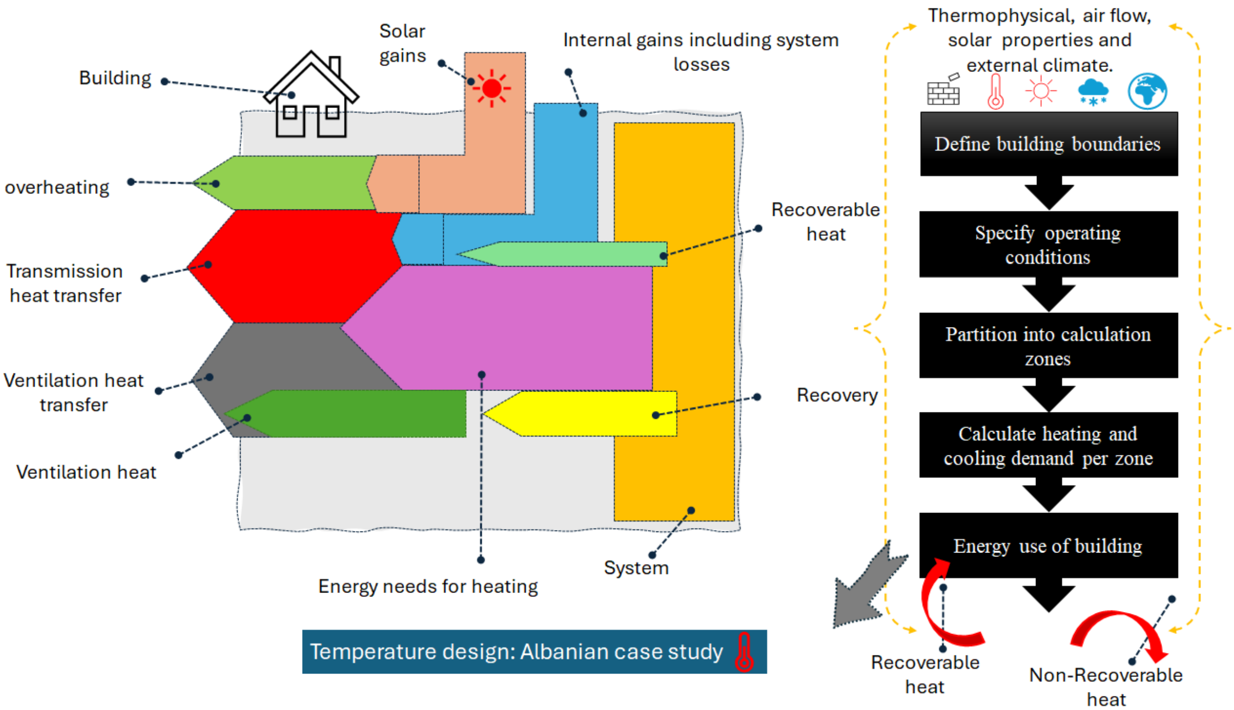

Fig. 1: The calculation procedures in EN ISO 13790 and the input/interaction with other standards, and a flow diagram showing the energy need for heating and cooling as a function of the energy balance. Adapted after [30]

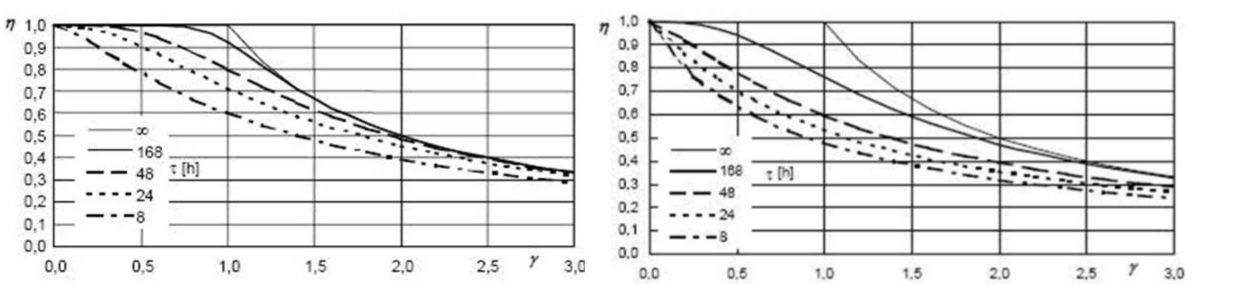

Fig. 2: Dependence of the internal energy use factor for the case: (a) Heavy construction and (b) light construction, [30]

Table 4. Key assumptions and parameters used in the tested buildings. Source: created by the authors

	Building categories
Thermal Insulation	No insulation, With insulation
Thermostat Set Points	Different temperature settings
Plant Operation	Continuous heating, Intermittent heating
Occupancy Type	Kindergarten, Housing and Office
Heating Mode	Underfloor heating (UFH), Radiator heating, Air heating
Internal Heat Gains	Considered based on occupancy, equipment features and usage

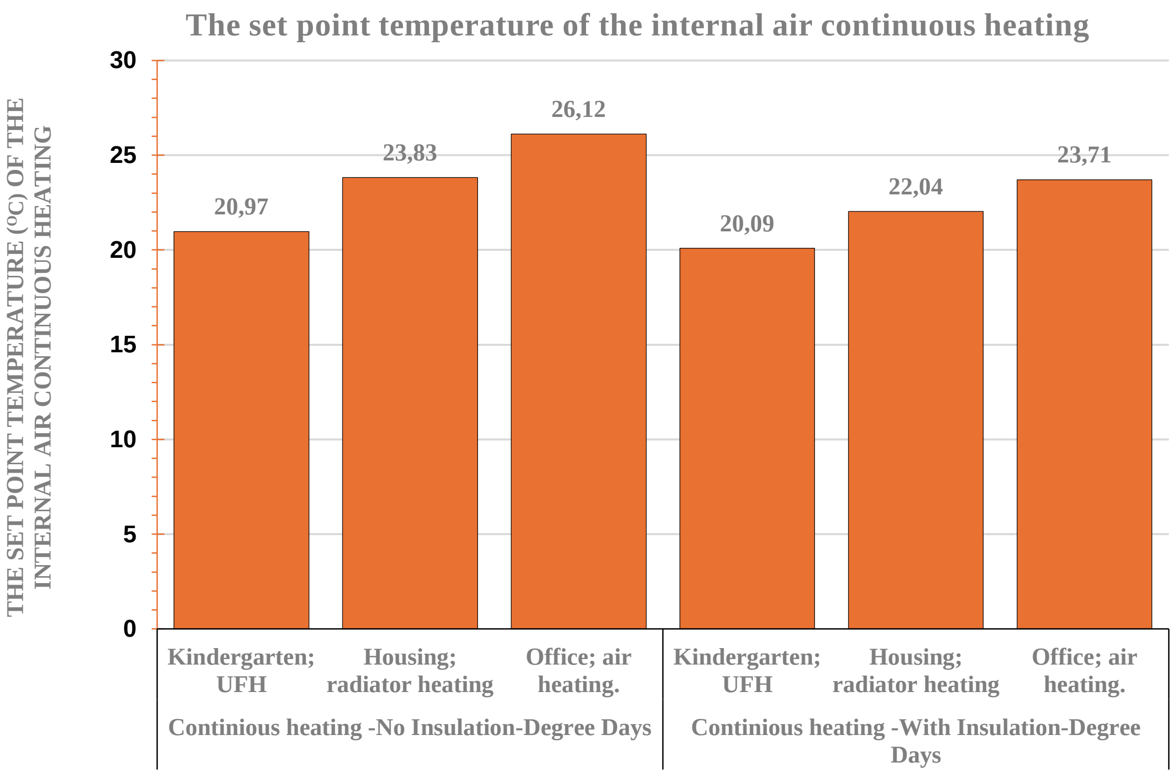

Fig. 3: The set point temperature of the internal air in continuous heating: the case without and with insulation

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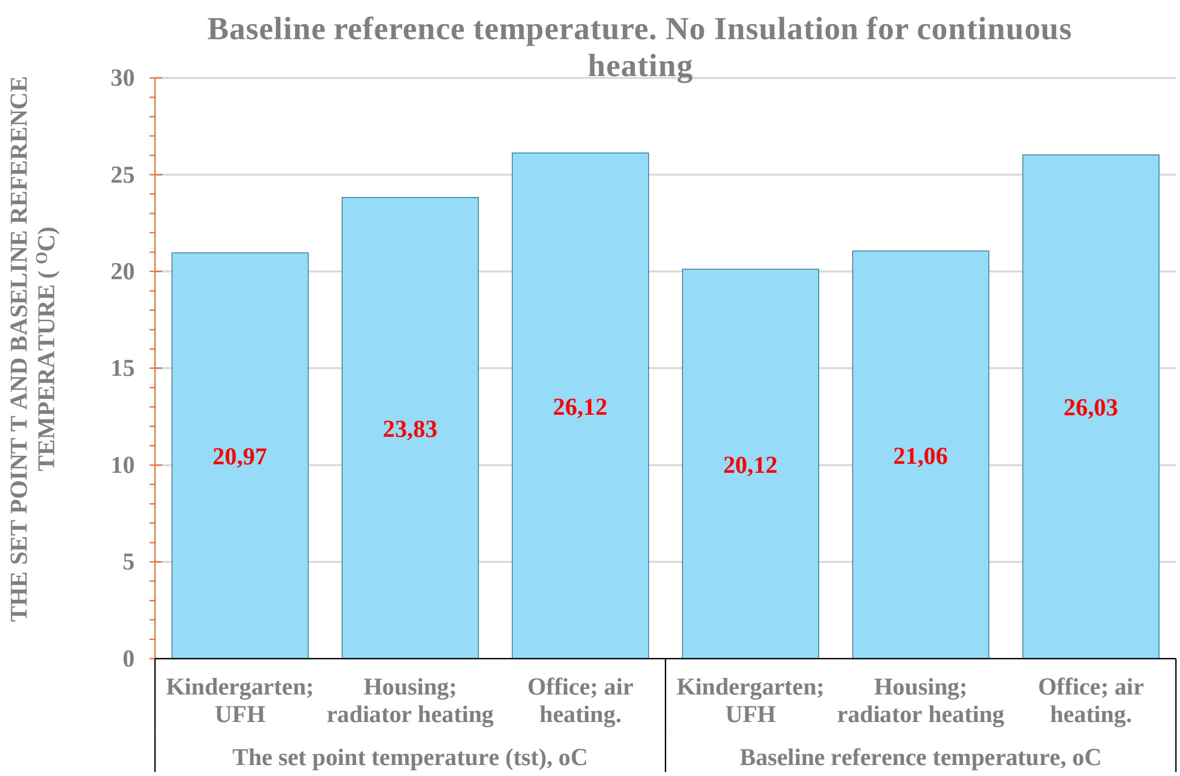

Fig. 4: Baseline reference temperature. No Insulation applied for the case of a continuous heating system

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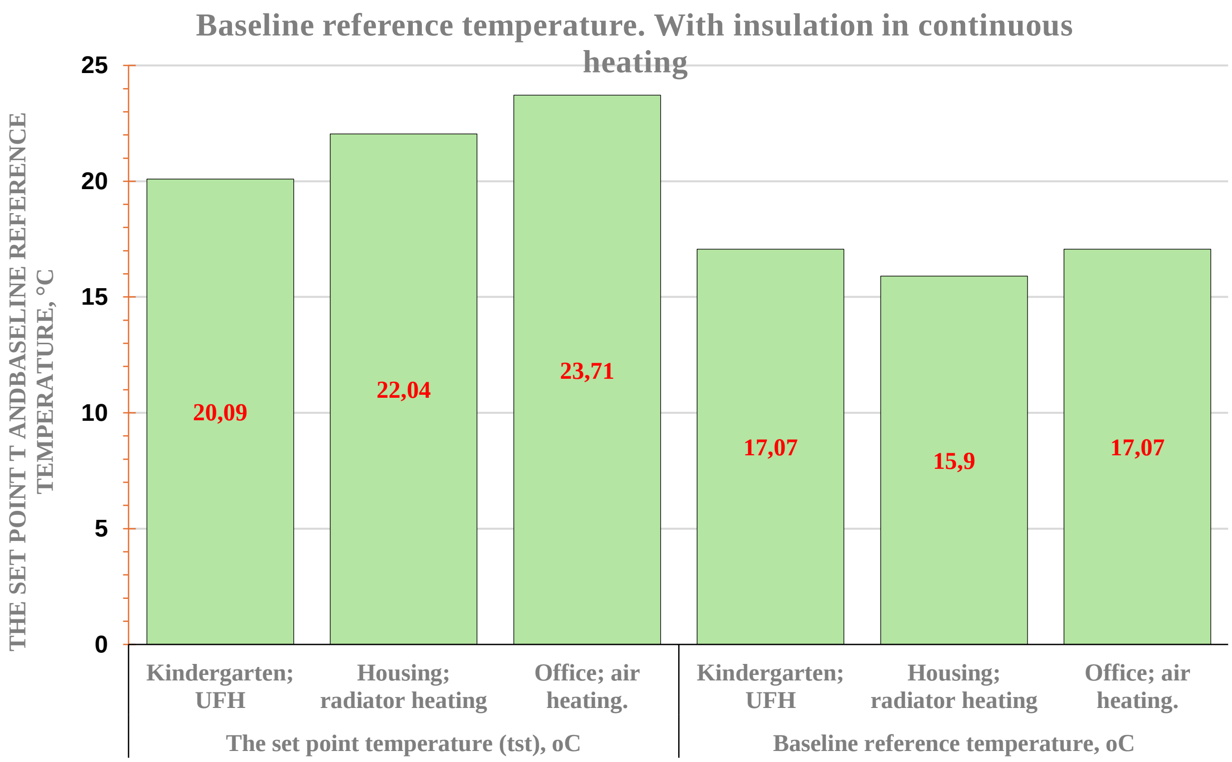

Fig. 5: Baseline reference temperature variation. With insulation applied for the case of a continuous heating *system*

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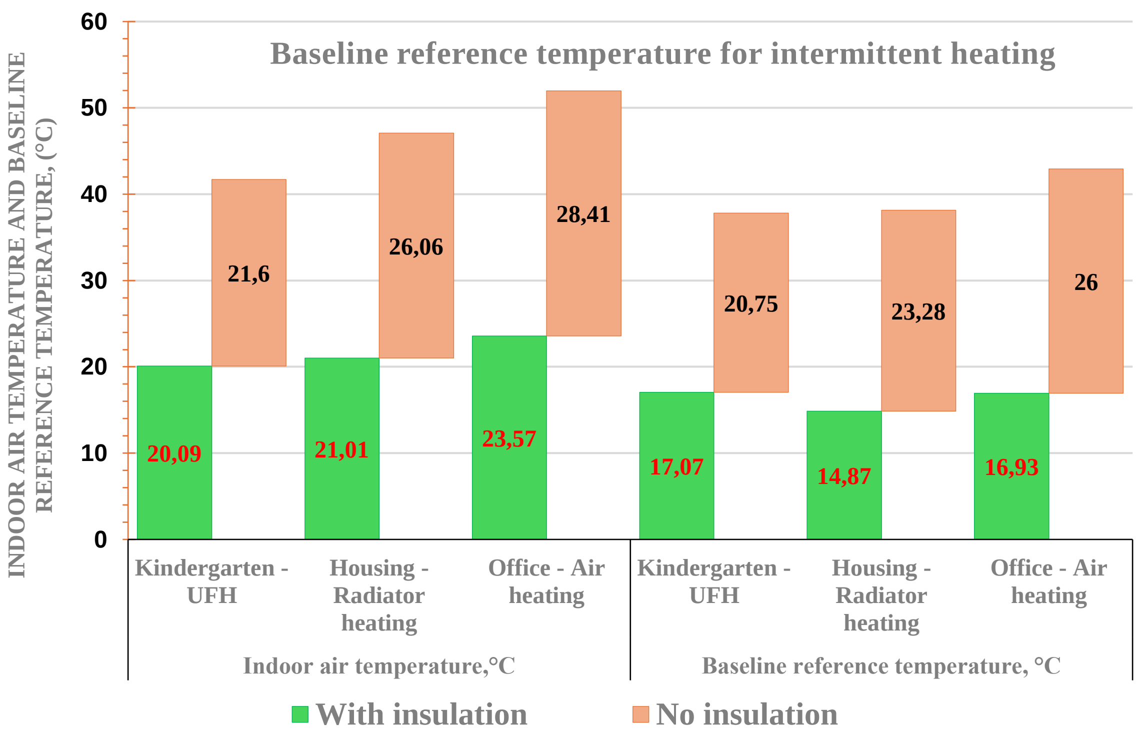

Fig. 6: Baseline reference temperature variation among three building categories chosen for the case of an intermittent heating system

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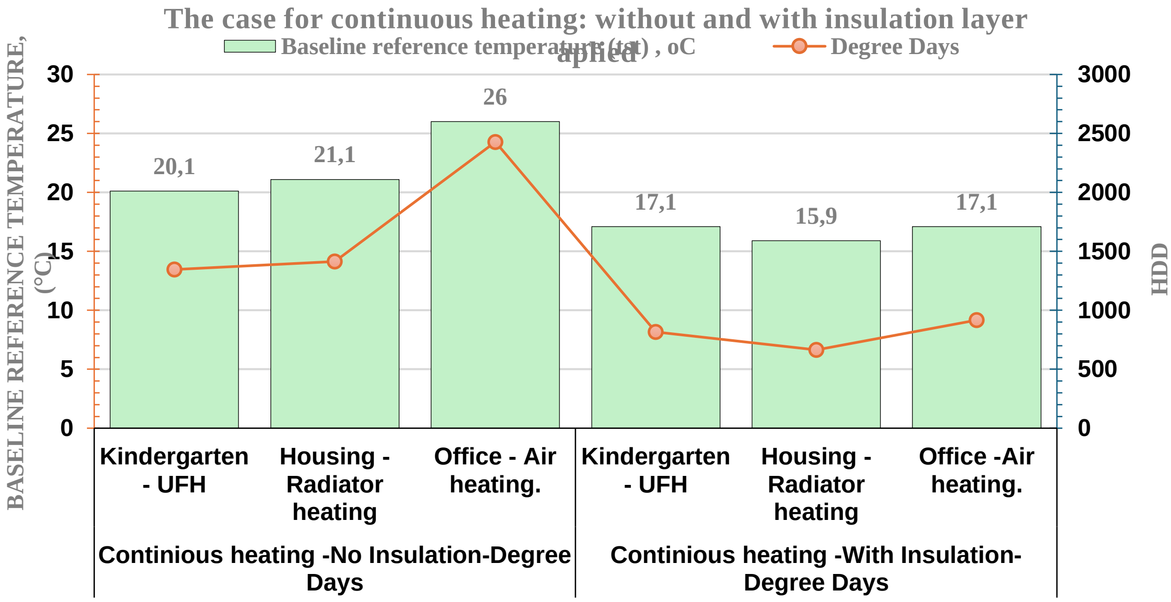

Fig. 7: Baseline reference temperature variation as a function of HDD for the chosen building categories without and with insulation, considering the case of continuous heating

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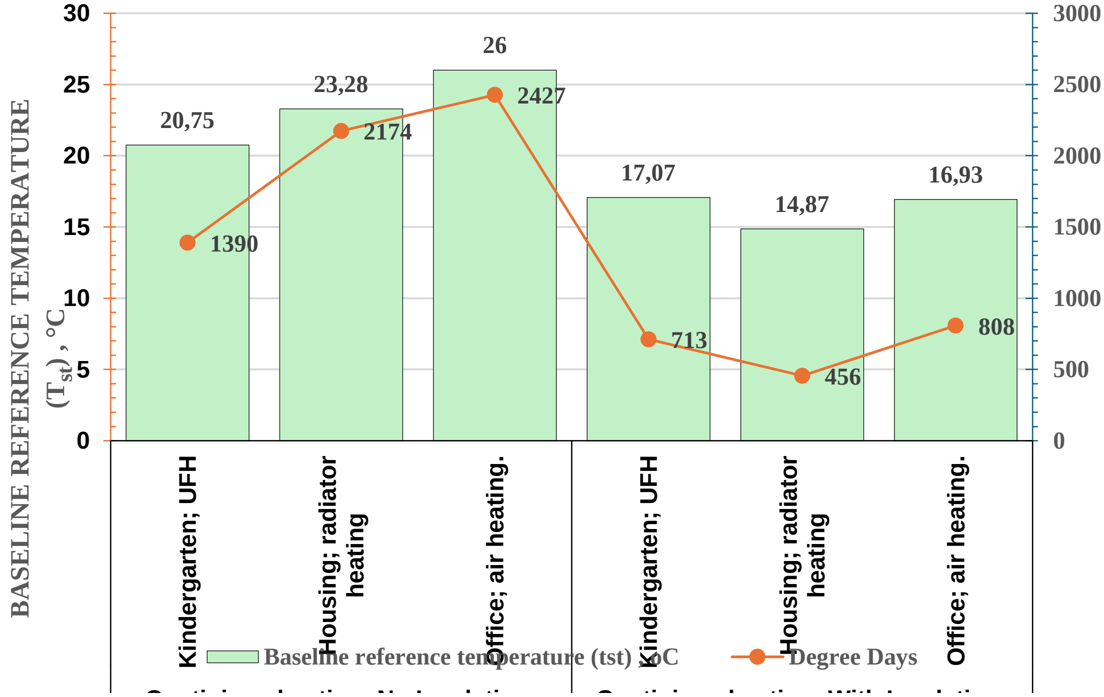

Fig. 8: Baseline reference temperature and HDD in the case with and without an insulation layer

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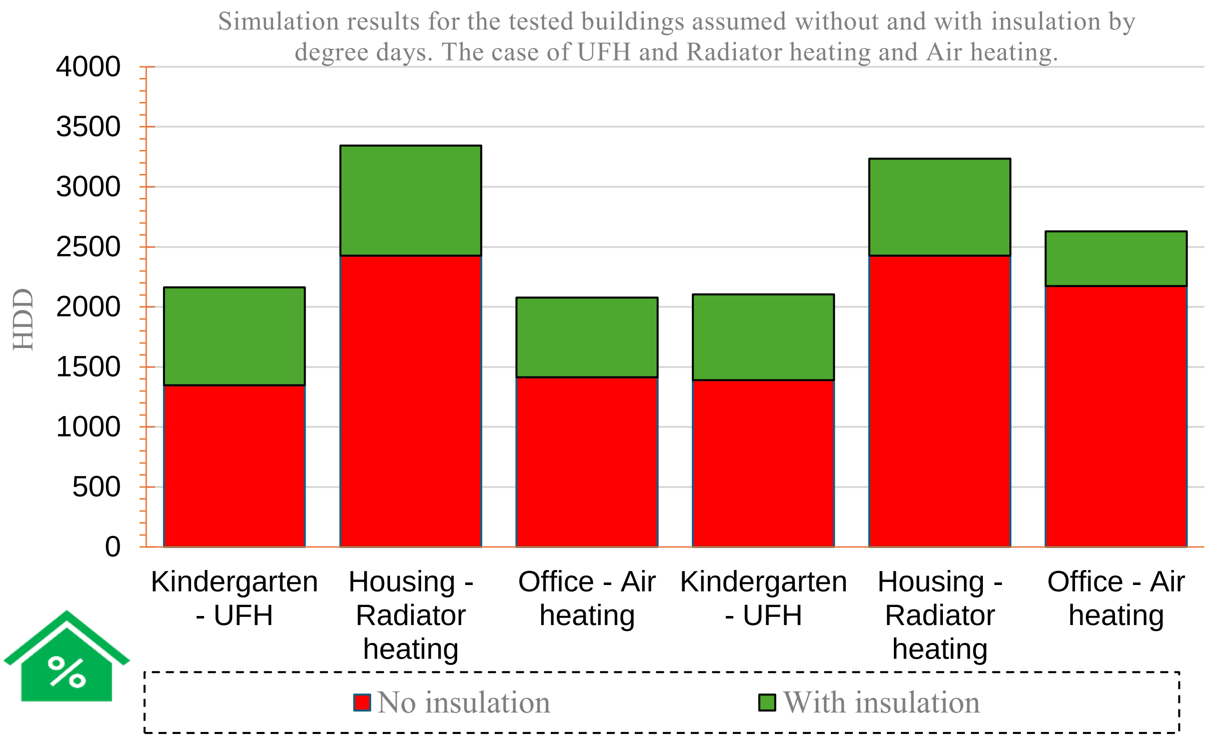

Fig. 9: Simulation results for the tested buildings assumed without and with insulation by degree days. The case of UFH and radiator heating and air heating
Source: Created by the authors