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# Climatic Adaptability and Energy Efficiency in European Container Houses

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**ABSTRACT**

Container Houses (CHs), leveraging shipping containers as their fundamental structural components, are increasingly popular for various compelling reasons. This innovative architectural solution, initially offering a more cost-effective alternative to traditional constructions, especially when employing recycled containers, has been enthusiastically embraced worldwide for its ability to provide quick, affordable, and environmentally friendly housing. The aim of this paper is to evaluate the energy efficiency of shipping container homes across various European locations, focusing on their adaptability in different climatic conditions. This study stands out by conducting a comprehensive analysis of the energy efficiency of different container house configurations in thirty distinct European locations. The novel aspect of this research lies in its detailed exploration of how climatic factors, geometric variations, and solar radiation exposure distinctively affect these homes, especially in the context of temporary housing. Moreover, the development of empirical correlations to calculate the thermal loads necessary for these innovative housing solutions represents a significant contribution to the design and planning of efficient and effective housing in diverse environmental settings. Utilizing Heating Degree Days (HDD) and Cooling Degree Days (CDD) concepts, the study delves into the exploration of climatic zones, integrating HDD, CDD, and solar irradiance data for a clearer view of climatic adaptability. The research employs dynamic simulations performed with the TRNSYS software, utilizing specific hourly climatic data for each location. Different CDD calculation methodologies are proposed and evaluated, establishing a baseline temperature for comfort and examining the thermal loads for various climatic contexts and geometric configurations of container houses. The findings reveal a significant correlation between climatic classification and the specific energy needs of container houses, emphasizing the impact of regional climatic characteristics on energy efficiency, particularly in small-sized dwellings like container houses. The analysis indicates the critical importance of conscious design and adaptation to local climatic contexts to ensure maximum energy efficiency. The proposed climate characterization model based on HDD, CDD, and solar irradiance finds an effective correlation with the Köppen-Geiger classification, especially in extreme climates, offering a new perspective for urban planning and housing design. The study underscores the importance of adaptive designs in developing sustainable, resilient architecture to meet contemporary environmental and societal challenges.

## 1. INTRODUCTION

Container Houses (CHs) are gaining traction due to their cost-effectiveness, especially when utilizing recycled containers [1]. These structures repurpose the over 17 million unused shipping containers globally, providing an eco-friendly and innovative housing solution [2]. CHs are popular for their quick assembly and flexibility, allowing easy modification and expansion of living spaces. Their robustness and modularity are ideal for residential and commercial use, applicable for both temporary and permanent setups [3-5].

A key advantage of CHs is their rapid deployment, making them ideal for post-disaster temporary housing (THs), as they offer immediate relief and facilitate recovery operations in disaster-stricken regions. This aspect was notably explored in a 2017 study which assessed the effectiveness of CHs in disaster scenarios [6].

Despite these benefits, challenges such as thermal and acoustic insulation, compliance with local building codes, and the management of thermal bridges due to container connections remain [7]. The building envelope of Container Houses (CHs), especially after a disaster, is examined for potentially compromising energy efficiency, which could impact the comfort and well-being of the residents [8-11].

Research by Tong Y et al highlighted the importance of proper insulation in CHs, showing that adherence to Nearly Zero-Energy Building (NZEB) standards could significantly reduce heating energy consumption [12]. Socially, CHs are being recognized for their potential in addressing homelessness, with increased interest from non-profits and social entrepreneurs in creating sustainable, low-cost housing solutions [13].

In Europe, the use of CHs is expanding due to their versatility and the strategic shifts in container usage prompted by initiatives like the One Belt One Road project. This has led to the adoption of CHs for various needs, including housing for refugees and student accommodations [14]. Energy efficiency studies in European contexts have also been conducted, focusing on adapting container homes to local climatic conditions and future environmental challenges [15].

This study evaluates the energy efficiency of container homes across various European locations, focusing on how these structures adapt to climatic variables. The proposed climate analysis, inspired by the approaches of Tsikaloudaki et al. [16], and incorporating principles from EN 15265 [17] and ISO 13790 [18], highlighted the specific thermal challenges for these regions. The study aims to optimize the configuration of container homes to improve energy efficiency and structural robustness, significantly contributing to the design of effective housing solutions in diverse environments.

## 2. METHODOLOGY

In this study, 30 areas spread across the European continent were analyzed. The site selection was carried out to ensure an even distribution across Europe, both geographically and climatically. Therefore, regions with colder climates, as well as those with temperate and warm conditions, have been identified. Table 1 displays the examined areas, along with their climate classification according to the Köppen-Geiger system [19].

**Table 1.** Areas of interest

| Köppen-Geiger Classification [19] | Locations | Climate |
|---|---|---|
| Cfb | Hamburg, Amsterdam, Bergen, Berlin, Copenhagen, Dublin, Gothenburg, London, Paris, Prague, Sofia, Stockholm, Warsaw, Vienna | Warm temperate |
| Csa | Athens, Barcelona, Cagliari, Istanbul, Lisbon, Marseille, Naples, Rome | Warm temperate |
| Cfa | Bucharest, Budapest | Warm temperate |
| Dfb | Helsinki | Boreal |
| Dfc | Tampere | Boreal |
| Bsk | Madrid | Arid |
| Csc | Milan, Zagreb | Warm temperate |

### 2.1 Container energy model

The container dimension has been carefully evaluated in the case study, considering international and European standards. The selected containers are from Hapag-Lloyd [20], one of the leading German-based global ocean carriers, serving approximately 23.700 customers on 121 routes worldwide [21].

The specifications are as follows:

- The shipping container has a length of 12.03 meters, a width of 2.35 meters, and a height of 2.39 meters.

The geometry of the container was developed using AutoCAD and SketchUp software [22] (Figure 1).

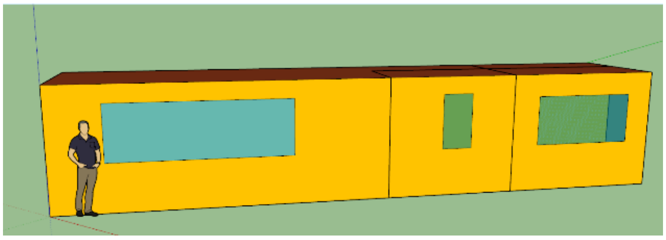

**Figure 1.** Container model

The analysis of the building components constituting the envelope of the CH is reported below. Two prefabricated sandwich panels of the aluminum/polyurethane type were considered, positioned side by side and connected by an additional layer of thicker polyurethane (Figure 2). This approach aligns with a similar stratigraphy investigated by Dumas et al. [11]. The alternating layers of steel and polyurethane are designed to deliver effective thermal insulation while ensuring robust structural resistance.

The choice of polyurethane was driven by its lightweight nature, contributing to the modularity of the structure, and facilitating the assembly and adaptability to the container's design. Table 2 lists the properties of the external wall considered in the study.

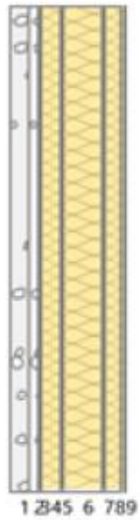


**Figure 2.** External wall stratigraphy

**Table 2.** Material properties for external wall

| No. | Layer | s (mm) | k (W/mK) | ρ (kg/m³) |
|---|---|---|---|---|
| | From the inside to the outside | | | |
| 1 | Plaster | 20 | 0.700 | 1400 |
| 2 | Plasterboard | 10 | 0.250 | 900 |
| 3 | Steel | 1 | 17.00 | 8000 |
| 4 | Polyurethane | 20 | 0.022 | 40 |
| 5 | Steel | 1 | 17.00 | 8000 |
| 6 | Polyurethane | 40 | 0.022 | 40 |
| 7 | Steel | 1 | 17.00 | 8000 |
| 8 | Polyurethane | 20 | 0.022 | 40 |
| 9 | Steel | 1 | 17.00 | 8000 |

In Table 3, the main characteristics of the building envelope are provided, including thermal transmittance, thickness, and the total solar transmittance factor (g-value) for windows.

**Table 3.** Main characteristics of the container envelope

| Building Element | Transmittance (W/m K) | Thickness (cm) | G-Value |
|---|---|---|---|
| External wall | 0.258 | 11.4 | - |
| External roof | 0.258 | 11.4 | - |
| Ground floor | 0.255 | 17.4 | - |
| Windows | 1.100 | - | 0.62 |

## 2.2 User description

To assess the heating and cooling thermal load of these buildings, thermal zones have been created in the TRNbuild [23] environment using the previously developed floor plans and architectural models. As shown in Table 4, "Single Module" configuration consists of 3 thermal zones:

**Table 4.** Interior area of the rooms

| Configuration | No. | Climatic Zone | S ($m^2$) |
|---|---|---|---|
| Single Module | 1 | OpenSpace | 17.46 |
| | 2 | Bathroom | 3.60 |
| | 3 | Bedroom | 7.17 |

For the identified scenario, the room usage profiles have been set with a heating set point temperature of 20°C from 9:00 AM to 8:00 PM. Outside of these hours, heating has not been planned. Similarly, a cooling set point of 26°C has been established for the same time frame, with no cooling provided for the remaining hours.

The same has been done for the assessment of the internal load due to people. A load of 60 kJ/h for the convective fraction and 6 kJ/h for the radiative fraction has been assigned for each occupant of the building according to the hourly occupancy profile.

## 2.3 Climate classification

The optimal management of energy consumption plays a fundamental role in sectors related to construction, especially when it comes to implementing innovative solutions such as container homes. In the European context where climatic variations can be significant from region to region, a thorough understanding of local climate patterns is essential to ensure energy efficiency and living comfort. In the context of this study, focus on this work on the climatic classification related to the use of container homes in Europe. Two fundamental metrics, Cooling Degree Days (CDD) and Heating Degree Days (HDD), will emerge as key indicators for the efficient design and optimized operation of container structures in response to climatic variations.

The goal is to explore how these metrics can influence the design and utilization of container homes, thereby contributing to the development of sustainable housing solutions adaptable to the specific climatic conditions of each European region.

Cooling Degree Days measure the thermal excess above a base temperature during warm climatic periods. On the other hand, Heating Degree Days assess the heating requirement based on temperatures below the base temperature selected for the heating period. The calculation is expressed as follows:

$$HDD = \sum_{I=1}^{365} (T_a - T_i)^+$$

$$CDD = \sum_{I=1}^{365} (T_i - T_b)^+$$

where, $T_i$ is the daily average air temperature; $T_a$ is the base temperature for calculating HDD; $T_b$ is the base temperature for calculating CDD.

The choice of the base temperature for calculating Heating Degree Days (HDD) and Cooling Degree Days (CDD) is influenced by several factors, including the specific human physiology of the region, energy supply, economic development level, and the characteristics of temperature changes. This variability is clearly reflected in the base temperatures adopted in different regions of the world. For instance, in the United States, the traditional value is 18.3°C, in the United Kingdom, it stands at 15.5°C, while in Germany, it is 15.0°C [24]. It is interesting to note that, despite these regional differences, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) establishes a common neutral base temperature of 18.3°C, which is applied in both heating and cooling contexts [25, 26]. This value is a result of empirical observations evaluated over extended periods which, have shown that internal and solar contributions tend to offset thermal loss when the average outdoor daily temperature is around 18°C. Additionally, the observations have shown that with respect to such temperature value energy consumption becomes proportional to the difference between the daily mean temperature and the base temperature [27].

## 2.4 Proposed method for climate characterizations

In this section, a simplified method to characterize the climate of thermal zones is presented, based on the parameters CDD, HDD18 (Heating Degree Days assessed with a base temperature Ta of 18.3°C), and solar irradiance.

For each parameter, different climatic zones have been categorized into six distinct groups, from "A" to "F," using quantiles. The categorization was performed separately for each parameter, providing a detailed and specific overview of the climatic characteristics of each zone. The reference ranges used for this categorization, specific to each parameter, are provided in the following tables: Table 5 for CDD, Table 6 for HDD, and Table 7 for solar irradiance. The values obtained for the respective ranges have been rounded to the nearest whole number.

**Table 5.** Cooling degree day ranges

| Category | Minimum CDD Range | Maximum CDD Range |
|---|---|---|
| A | 300 | - |
| B | 211 | 299 |
| C | 91 | 210 |
| D | 35 | 90 |
| E | 14 | 34 |
| F | 0 | 13 |

**Table 6.** Heating degree day ranges

| Category | Minimum HDD Range | Maximum HDD Range |
|---|---|---|
| A | - | 1464 |
| B | 1465 | 2726 |
| C | 2727 | 3105 |
| D | 3106 | 3320 |
| E | 3321 | 3822 |
| F | 3823 | - |

**Table 7.** Irradiance ranges

| Category | Minimum Irradiance Range | Maximum Irradiance Range |
|---|---|---|
| A | 161 | - |
| B | 145 | 160 |
| C | 129 | 144 |
| D | 114 | 128 |
| E | 98 | 113 |
| F | - | 97 |

Starting from the initial characterizations based on individual climatic parameters - Cooling Degree Days (CDD), Solar Irradiance, and Heating Degree Days (HDD) - a comprehensive and integrated climatic classification has been developed. This classification aims to provide a more holistic understanding of the needs and climatic characteristics of each location.

## 3. RESULTS

The process for developing the final climate classification, integrating the three parameters analyzed in the previous section, involved the following steps.

1) Initially, each location was categorized based on the three individual parameters. For Cooling Degree Days (CDD) and Solar Irradiance, higher values indicative of warmer and sunnier conditions were assigned to Category A, descending to Category F for lower values. Conversely, for Heating Degree Days (HDD), Category A represented lower values indicating milder conditions, ascending to Category F for higher values.

2) Next, the alphabetical categories were converted into numerical values. In this scale, A equated to 1, B to 2, and so forth. A combined climate category for each location was determined by calculating the average of these numerical values across the three parameters.

3) Finally, the average numerical values were rounded to the nearest whole number and reconverted into alphabetical categories. This resulted in the final combined climate classification for each location.

The resulting combined climate classification for each location is presented in the following.

In a comparative analysis with the Köppen-Geiger climate classification in Figure 3, various observations are made:

- Warm Climates (Category A): It is observed that locations classified in Category A generally tend to correspond to the Köppen-Geiger categories Csa and Bsk, indicative of Mediterranean and semi-arid climates. This suggests a reasonable alignment for the warmer areas.

- Moderate Climates (Categories B, C, and D): In these categories, a wide range of correspondence with the Köppen-Geiger classifications is highlighted, reflecting the diversified nature of temperate and transitional climates.

- Cold Climates (Category F): A more pronounced alignment is noted for cold climates, where Category F aligns well with Köppen-Geiger's Dfc and Dfb categories, indicating continental and subarctic climates.

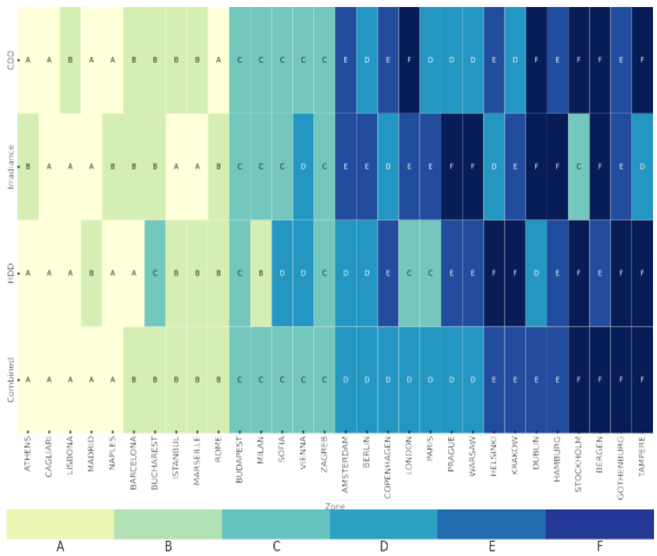


**Figure 3.** Climatic classification for each zone

The integrated climate classification provides a simplified yet well-defined perspective on climate needs, proving particularly beneficial in residential contexts for heating and cooling evaluations. While this classification aligns commendably with the Köppen-Geiger system for extreme climates, it is important to emphasize that its simplified nature becomes more apparent in temperate zones. In these areas, indeed, the Köppen-Geiger classification manages to provide a more meticulous and detailed distinction.

### 3.1 Energy analysis

The analysis, involving a single container, included the 30 locations identified in the preceding paragraphs. The primary objective of the analysis is to assess the heating and cooling load associated with each of the considered locations (Figure 4), in order to provide a detailed insight into the energy performance of the container in various environmental contexts. The data shows that heating loads are significantly higher in colder climates, as expected. For example, Nordic cities like Helsinki, Stockholm, and Gothenburg exhibit considerably high heating loads, while Mediterranean cities like Athens and Naples present more significant cooling loads. This highlights the importance of adapting energy management strategies to the specific climatic needs of each location.

Another interesting aspect is the impact of solar irradiance on energy loads. Cities with high levels of solar irradiance, such as Lisbon, show higher cooling loads. This suggests that implementing solutions such as shading, natural ventilation, and thermal insulation can be crucial for improving living comfort and reducing energy consumption in these areas.

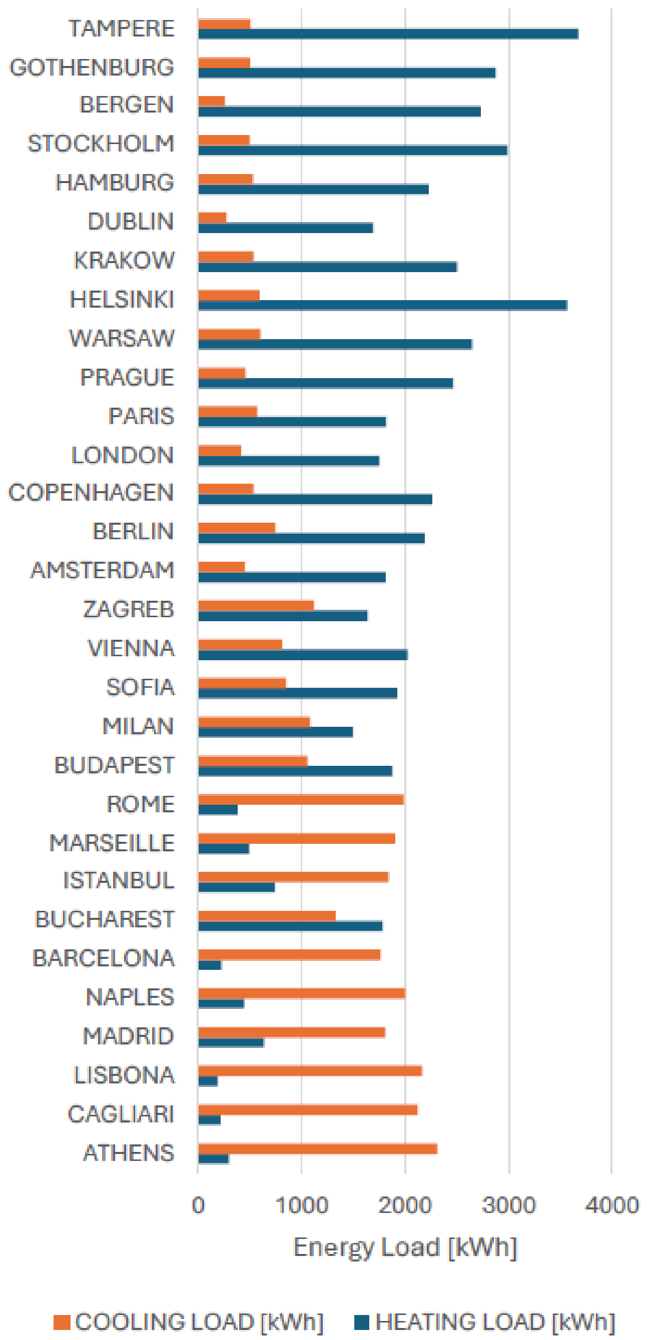


**Figure 4.** Energy load [kWh]

The analysis of the climatic classification of different locations, based on parameters such as Cooling Degree Days (CDD), Heating Degree Days (HDD), and average solar irradiance, has proven to be consistent with the specific energy requirements of container homes in each location. It is crucial to highlight that there are significant correlations between the calculated thermal loads for container homes and the parameters used in the classification outlined in the previous section. The subsequent figures convincingly demonstrate the validity of this correlation.

Figure 5 displays a scatter plot correlating Cooling Degree Days (CDD) with Heating Degree Days (HDD) at a specific base temperature (Tb = 18.3°C). The data points, depicted as orange circles, represent pairs of CDD and HDD values for different locations. The curve, fitted by a quadratic equation, aligns with the data points, and indicates an inverse relationship between CDD and HDD: as the number of heating days (HDD) increases, the cooling days (CDD) decrease, and vice versa. The coefficient of determination ($R^2$ = 0.8308) signifies a good fit of the model to the observed data.

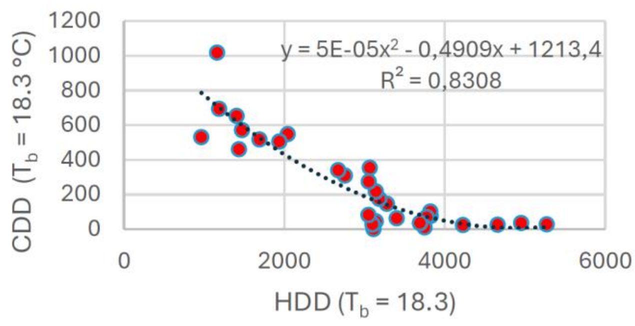


**Figure 5.** Correlation analysis: CDD18 and HDD18

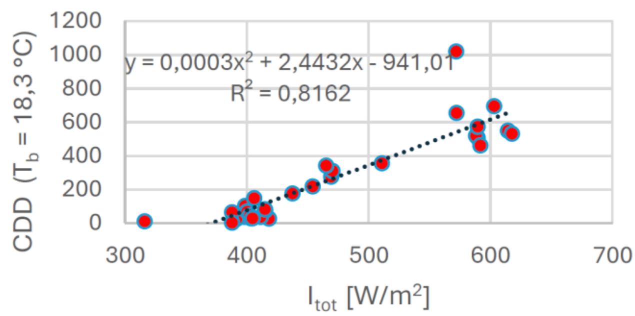


**Figure 6.** Correlation analysis: CDD and annual average total solar irradiance $I_{tot}$

Figure 6 shows a scatter plot illustrating the relationship between Cooling Degree Days (CDD) and the annual average of total solar irradiance. The curve, fitted with a quadratic equation, indicates a direct correlation where increased solar irradiance correlates with increased CDD, which is consistent with the notion that higher solar irradiance leads to greater cooling requirements. The model's fit is good, with an $R^2$ value of 0.8162.

Figure 7 depicts the correlation between Heating Degree Days (HDD) and the annual heating load. The scatter plot, also modeled by a quadratic equation, demonstrates a strong positive correlation, indicating that higher HDD values are associated with higher heating loads. The fit of the model is very strong, as reflected by the $R^2$ value of 0.9827.

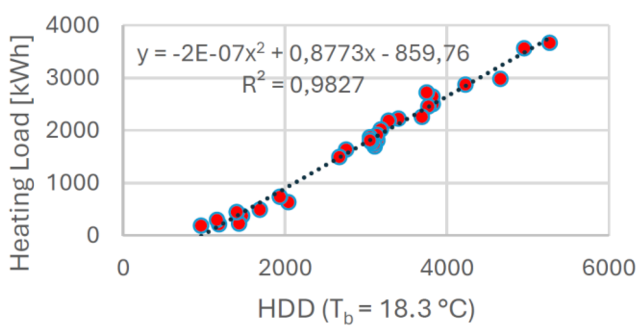


**Figure 7.** Correlation analysis: Heating load and HDD18

Lastly, Figure 8 presents a scatter plot that relates CDD to the annual cooling load. This relationship is shown to be positively correlated as well, with higher CDD values leading to increased cooling loads. The quadratic model shows an excellent fit with an $R^2$ value of 0.9655, underscoring the predictive strength of the climatic parameters for cooling energy requirements.

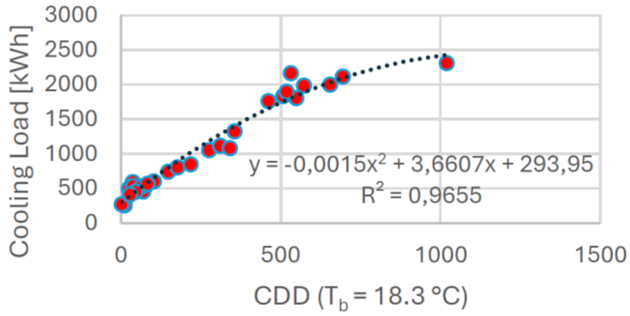


**Figure 8.** Correlation analysis: Cooling load and CDD18

To illustrate the alignment between the observed thermal needs and the employed climatic classification, Figure 9 presents a clear depiction of the thermal requirements for the locations under study, categorized by each climatic zone. This analysis showcases how the findings are systematically and incrementally arranged in line with the chosen classification, revealing a logical and structured correlation between the energy demands and the climatic features of the various regions.

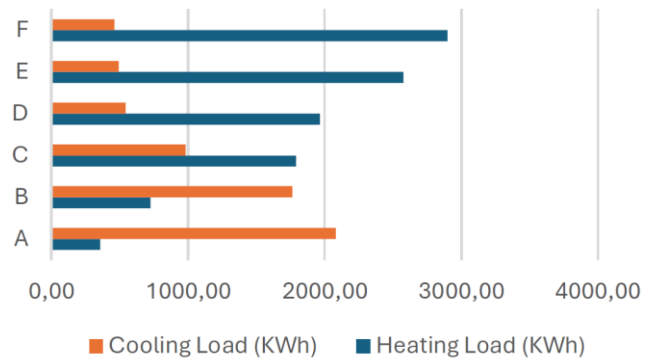


**Figure 9.** Average heating and cooling load by climate category

## 4. CONCLUSIONS

The paper provides a comprehensive analysis of the energy efficiency of a container house in thirty European locations. The primary objective is to evaluate the adaptability of these residences to various climatic conditions, including climatic characterization (CZB), and compare it with the Köppen-Geiger system.

In the context of the study, a climate characterization model was developed using Heating Degree Days (HDD), Cooling Degree Days (CDD), and solar irradiance. The analysis revealed a significant correlation with the Köppen-Geiger classification, particularly in extreme climatic zones. This model emerges as a potentially effective tool for climate characterization in residential applications, opening new perspectives for urban planning and housing design.

Additionally, the study examined the heating and cooling loads in different locations, highlighting a clear correlation between climatic classification and the specific energy requirements of container houses. This emphasizes how regional climatic characteristics can directly impact energy efficiency, especially in smaller residences like container houses. A significant contribution of this research was the development of empirical correlations to calculate the thermal loads required for these innovative housing solutions. These correlations serve as practical and useful tools for evaluating the energy efficiency of container houses in various climatic conditions, which is crucial for designing and planning sustainable and adaptable housing while considering the variability of environmental conditions.

The conclusions of this research clearly indicate that a holistic approach, considering both energy efficiency and the well-being of inhabitants, is essential for developing sustainable, adaptable, and comfortable housing solutions. This approach is fundamental in addressing contemporary challenges related to the environment and society.

Extended future work could evaluate the impact of different container house geometries to identify the correct correlation between heating/cooling demand and geometry for each climatic zone.

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## NOMENCLATURE

### *Abbreviations*

| | |
|---|---|
| ***CHs*** | Container Houses |
| ***THs*** | Temporary Housing |
| ***CZB*** | Climatic Zoning for Buildings |

### *Degree Days and Related Temperatures*

| | |
|---|---|
| ***HDD*** | Heating Degree Days |
| ***CDD*** | Cooling Degree Days |
| ***HDD18*** | Heating Degree Days (Base temperature of 18.3℃) |
| ***CDD18*** | Cooling Degree Days (Base temperature of 18.3℃) |

| | |
|---|---|
| ***T*** | ***K*** |
| ***Ta*** | Base Temperature for calculating HDD (K) |
| ***Tb*** | Base Temperature for calculating CDD (K) |

***Thermal Parameters***

| | |
|---|---|
| ***c*** | J/(kg K) |
| ***k*** | W/(m K) |
| **ρ** | Density, $kg/m^3$ |
| **g-value** | Total Solar Transmittance factor |
| $\mathbf{I_{tot}}$ | Total solar irradiance, $W/m^2$ |

***Köppen Climate Classification***

| | |
|---|---|
| **Cfb** | Temperate oceanic climate with mild summer |
| **Csa** | Mediterranean climate with hot summer |
| **Cfa** | Humid subtropical climate |
| **Dfb** | Humid continental climate with warm summer |
| **Bsk** | Cold semi-arid climate |
| **Dfc** | Subarctic climate with cool, short summer |
| **Csc** | Mediterranean climate with cool summer |