Research Article

GAZİ JOURNAL OF ENGINEERING SCIENCES

# The Energy Analysis for Net Zero Energy Building Using Hourly Analysis Program: A Case Study of a Residential Building In Baghdad

Lara Raad Jawad Al-Shammari [a], Mutlu Tekir [*b]

Submitted: 11.10.2024 Revised : 27.12.2024 Accepted: 03.01.2025 doi:10.30855/gmbd.070525N06

**Keywords:** Net zero energy building, insulation, coating, thermal load, hourly analysis program

[a] Karabuk University, Engineering Faculty, Dept. of Mechanical Engineering 78000 - Karabuk, Türkiye Orcid: 0000-0002-0352-207X

[b,*] Karabuk University, Engineering Faculty, Dept. of Biomedical Engineering 78000 - Karabuk, Türkiye Orcid: 0000-0003-2289-7034 e mail: mutlutekir@karabuk.edu.tr

[*]Corresponding author: mutlutekir@karabuk.edu.tr

## ABSTRACT

This study addresses the critical challenge of reducing energy consumption in residential buildings, particularly in extreme climates like Baghdad, where thermal loads are substantial during summer and winter. Conventional construction methods often fall short in achieving energy efficiency, necessitating innovative approaches. This work evaluates alternative solutions such as exterior insulation, reflective coatings, and renewable energy systems. The study highlights a novel perspective by integrating advanced simulations using HAP and TRACE 700 to analyze thermal performance and validate findings. Key results demonstrate the pivotal role of insulation in achieving energy efficiency: cooling loads in a living room decreased from 6.8 kW to 3 kW, while heating loads reduced from 3.3 kW to 1.6 kW with insulation. The choice of reflective coatings further influenced thermal loads, though to a lesser degree. Solar energy integration proved vital in balancing the Variable Refrigerant Flow (VRF) system's energy demands, requiring 5.94 kW in summer and 3.66 kW in winter. A variance of 5% between simulation tools confirmed the reliability of the results. This research provides actionable insights into sustainable building practices, emphasizing the transformative potential of insulation and renewable energy in reducing carbon footprints and achieving net-zero energy goals.

# Hourly Analysis Program Kullanarak Net Sıfır Enerji Binası İçin Enerji Analizi: Bağdat'ta Bir Konut Binası Üzerine Bir Vaka Çalışması

## ÖZ

Bu çalışma, yaz ve kış aylarında termal yüklerin yüksek olduğu Bağdat gibi ekstrem iklimlerde enerji tüketimini azaltma konusundaki kritik zorlukları ele almaktadır. Geleneksel inşaat yöntemleri enerji verimliliğini sağlama konusunda yetersiz kalmakta, bu nedenle yenilikçi yaklaşımlar gerekmektedir. Bu çalışma, dış cephe yalıtımı, yansıtıcı kaplamalar ve yenilenebilir enerji sistemleri gibi alternatif çözümleri değerlendirmektedir. Ayrıca, gelişmiş simülasyon tekniklerini (HAP ve TRACE 700) kullanarak termal performansı analiz eden ve bulguları doğrulayan yeni bir perspektif sunmaktadır. Ana bulgular, enerji verimliliği sağlama konusunda yalıtımın kilit rolünü ortaya koymaktadır: oturma odasında yalıtım ile soğutma yükleri 6,8 kW'tan 3 kW'a, ısıtma yükleri ise 3,3 kW'tan 1,6 kW'a düşmüştür. Yansıtıcı kaplama tercihleri de termal yükleri etkilemiş, ancak daha az ölçüde. Yenilenebilir enerji entegrasyonu, Değişken Soğutucu Akışkan (VRF) sisteminin enerji talebini dengelemede hayati bir rol oynamış ve yazın 5,94 kW, kışın ise 3,66 kW enerji ihtiyacı belirlenmiştir. Simülasyon araçları arasında %5'lik bir fark, sonuçların güvenilirliğini doğrulamıştır. Bu araştırma, sürdürülebilir bina uygulamaları konusunda uygulanabilir bilgiler sunmakta ve yalıtım ile yenilenebilir enerjinin karbon ayak izini azaltma ve net sıfır enerji hedeflerine ulaşma konusundaki dönüştürücü potansiyelini vurgulamaktadır.

**Anahtar Kelimeler:** Net sıfır enerji binası, yalıtım, kaplama, ısı yükü, hourly analysis program

**To cite this article** : L. R. J. Al-Shammari and M. Tekir, "The Energy Analysis For Net Zero Energy Building Using Hourly Analysis Program: A Case Study of a Residential Building in Baghdad," Gazi Journal of Engineering Sciences, vol.11, no.1, pp. 83-103, 2025. doi:10.30855/gmbd.070525N06

# 1. Introduction

In 2021, emissions from heating buildings accounted for 80% of all direct $CO_2$ emissions in the building industry. However, heating-related $CO_2$ emissions have only increased by 1.5% since 2010. To achieve net-zero goals, the rate of improvement in energy efficiency must accelerate, with the $CO_2$ intensity of heated homes needing to decrease by nearly 10% per year until 2030. Heating and cooling systems are critical components of modern construction, designed to maintain indoor comfort in various climates. Understanding the basics of these systems is essential for sustainable construction methods. Heating systems include forced air, boilers, heat pumps, hybrid heating, ductless mini-splits, radiant heating, and baseboard heaters [1].

Air conditioning is vital for cooling and dehumidifying large buildings and homes. Split systems, with separate evaporator and condenser units, as well as variable refrigerant flow (VRF) systems, offer flexibility and convenience. Chilled water systems generate cold water for cooling, while evaporative cooling systems use water evaporation to cool air [2]. Radiant cooling systems cool building surfaces using water, and passive cooling systems harness outdoor air to cool interior spaces. Zero-energy buildings (ZEBs) aim to balance energy consumption with renewable energy generation, using solar panels, wind turbines, and geothermal systems. These buildings rely on advanced insulation, efficient lighting, and smart technologies to optimize energy use. Additionally, passive design strategies, sustainable materials, and landscaping contribute to reducing the environmental impact of NZEBs [3].

## 1.1. Zero energy buildings

A net-zero energy building (NZEB) is designed to produce as much energy as it consumes annually, minimizing environmental impact and maximizing energy efficiency [4]. Key features of NZEBs include energy-efficient design, integration of renewable energy sources, advanced energy monitoring and management systems, passive design strategies, and energy storage solutions. Achieving net-zero energy requires a holistic approach, encompassing every aspect of building design, construction, and operation [5].

ZEBs play a crucial role in reducing the environmental impact of the built environment and combating climate change. However, many people, even in developed countries, face challenges due to a lack of electricity and adequate housing. To meet their energy needs, ZEBs rely on on-site energy generation through microgeneration technologies such as solar power, wind turbines, biomass, sewage gas, waste heat, and other renewable sources [6].

On the other hand, challenges such as financial constraints, workmanship errors, and insulation not providing the expected efficiency can undermine the intended energy savings of ZEBs in the real field. These issues can lead to financial losses, costly repairs, and operational inefficiencies, preventing buildings from achieving their intended net-zero status [7-8].

The Home Energy Rating System (HERS) is a standardized method used in the United States to assess the energy efficiency of homes and predict future energy use [9]. The U.S. Department of Energy recommends conducting a HERS assessment, which provides recommendations for cost-effective energy improvements and estimates anticipated energy savings [10].

Building environmentally friendly homes requires careful planning and design. Buildings should be well-insulated and airtight to minimize energy consumption. Although the upfront cost of electric heating and cooling systems can be high, they offer a more sustainable alternative in the long run as the energy grid shifts towards renewable sources. Energy analysis is critical for evaluating efficiency, environmental impact, and cost-effectiveness. Buildings should be appropriately sized, monitored, and equipped with advanced control systems and variable speed drives to optimize performance [11]. Heating systems can be further optimized by reducing energy consumption, evaluating energy sources, and integrating renewable energy technologies. Regular maintenance, programmable thermostats, and heat recovery systems also help reduce energy use and improve overall efficiency. As the global energy system transitions toward renewables, using electricity for heating becomes the only sustainable option [12].

In regions with high heating demands, meeting energy needs through renewable sources becomes more difficult, especially since solar energy is scarce during the heating season. As a result, a significant portion of heating energy in densely populated areas still comes directly or indirectly from fossil fuels. The European Union has estimated that around 2000 TWh of seasonal energy storage would be required to meet winter heating demands if reliance on fossil fuels is reduced [13,14]. Germany alone would need around 40 TWh of seasonal storage [15]. Zero-energy buildings can help address these challenges by reducing the need for additional infrastructure and offering energy solutions that are less reliant on conventional heating systems [16].

Greenhouse gas emissions from electricity and heating are often reported together, making it difficult to isolate the contribution from heating alone. However, estimates suggest that heating and electricity together account for about 45% of emissions, far exceeding emissions from transportation, which contribute around 28% [17]. Approximately half of these emissions come from homes, businesses, schools, and other public and private buildings.

According to research conducted in 2014, around 70% of energy consumption in the residential sector is derived from fossil fuels. Central heating systems, such as forced steam boilers and hot water or air furnaces with radiators, typically rely on fossil fuels like natural gas [18].

### 1.2. Building envelopes

Overall Thermal Transfer Value (OTTV) is a metric that quantifies the average rate of heat transfer into a building through its envelope, encompassing walls, windows, and roofs. It serves as an index for comparing thermal performance of buildings, with lower OTTV values indicating better energy efficiency. Envelope Thermal Transfer Value (ETTV) is a similar measure, focusing specifically on the heat transfer through the building's envelope, excluding the roof. Both OTTV and ETTV are utilized in building codes and standards to regulate and enhance the energy efficiency of structures. Systematic Evaluation on Energy and Thermal Performance (EETP) is a comprehensive assessment approach that evaluates a building's energy consumption and thermal characteristics. While OTTV and ETTV concentrate on the building envelope's thermal properties, EETP encompasses a broader analysis, including factors like mechanical systems, occupancy patterns, and overall energy usage. This holistic evaluation aids in identifying areas for improvement to achieve optimal energy efficiency and occupant comfort [19-20].

Building envelope design takes local weather patterns into consideration, evaluating thermal effectiveness using indices like Overall Thermal Transfer Value (OTTV), systematic evaluation on energy and thermal Performance (EETP), and Envelope Thermal Transfer Value (ETTV) for subtropical and hot summer/cold winter zones. Chua et al. [21] emphasize a bioclimatic approach that focuses on passive design tailored to different climate zones, minimizing heating and cooling energy consumption through four energy-efficient building envelope measures. They found 4% reduction in cooling energy consumption in Singapore according to their analyses.

Daouas et al. [22] evaluates the optimum insulation thickness, energy savings, and payback period for external walls in Tunisia's climate, considering both heating and cooling demands. Using the Complex Finite Fourier Transform (CFFT) method and life-cycle cost analysis, the results highlight that wall orientation significantly impacts energy savings, with the south-facing wall being the most economical, achieving 71.33% energy savings. They also highlight that insulation is more effective in colder regions for heating-dominated buildings and less effective in warmer climates. However, over-insulation may lead to increased cooling needs and energy consumption. The optimal insulation thickness is typically determined through cost and energy efficiency analyses. Many designers and researchers employ thermal mass strategies to reduce interior temperatures during the day, with recent studies focusing on sensitivity analysis. Integrating nighttime ventilation with thermal mass optimizes energy conservation [23]. Artmann et al. [24] propose a design method for moderate or cold climates of Central, Eastern and Northern Europe that prevents excessive summer heating and reduces the cooling load, thus potentially mitigating the effects of climate change on the indoor environment.

Tian et al. [25] propose balancing daylight and solar apertures in and glazing design, incorporating generalized energy rating systems for sustainable building development. Boixo et al. [26] found that greening rooftops in Andalusia, Spain, could save 295 MWh of power annually, though limited roof space may hinder the deployment of renewable energy systems. Biggest savings are achieved in mild climates with up to 48%, and savings of flat dark roof of old buildings are greater.

### 1.3. Renewable energy and other technologies

Despite advanced energy reduction strategies, buildings still require energy for daily operations, which in Zero-Emission Buildings (ZEBs) is provided by sustainable energy technologies. These include both on-site and off-site solutions. Cheng et al. [27] describe a hybrid photovoltaic thermal system that improves photovoltaic (PV) efficiency by using a thermoelectric cooling module to lower the temperature of solar cells, thus generating both thermal and electrical energy. Strzalka et al. [28] suggest that integrating photovoltaic systems into the grid can generate on-site electricity, reducing $CO_2$ emissions and lessening reliance on fossil fuels. This approach enhances the use of renewable energy in urban areas and produce 35% of total electricity consumption. Foley et al. [29] indicate that wind and solar energy can complement each other, enabling the construction of hybrid PV-wind power systems, which provide superior energy performance.

### 1.4. Building insulation

Buildings account for approximately 40% of total energy consumption in the UK, prompting significant efforts to reduce energy use and greenhouse gas emissions through energy-efficient retrofitting. Recent studies emphasize the importance of enhancing building envelopes with advanced materials like aerogel [30], insulation plaster [31], bamboo fibre reinforced briquettes [32], hollow bricks [33] for optimal thermal performance, demonstrated by substantial reductions in heat loss coefficients and thermal bridging effects in retrofitted structures.

Azkorra et al. [34] point to the benefits of insulation, which reduces energy consumption and improves thermal comfort. Green walls, in particular, are promising for enhancing urban quality of life and reducing noise, though their sound insulation capabilities require further study. In Malaysia, increased electricity usage led researchers to assess the long-term environmental impact of various insulation materials. Shekarchian et al. [35] found that 2.2 cm of fiberglass-urethane insulation provides cost savings and reduces annual $CO_2$ emissions by 16.4 kg/m$^2$, with renewable power plants and the phasing out of thermal coal also contributing. Dombayci [36] highlights the importance of insulation in Denizli, Turkey's third climatic region, where heating is required for five months each year. The study explored the environmental benefits of optimal insulation thickness using coal as fuel and expanded polystyrene as an insulating material, showing that optimal insulation reduced energy usage by 46.6% and $CO_2$ and $SO_2$ emissions by 41.53%. Bolattürk [37] examined the optimal insulation thickness for Turkey's coldest cities (Erzurum, Kars, and Erzincan), using a life-cycle cost-benefit analysis. In Erzurum, the optimal insulation thickness can result in savings of up to \$12.11/m$^2$ of wall area. Insulation continues to gain popularity due to its significant impact on the environment and high energy costs.

This focus on insulation methods is further supported by studies exploring the application of advanced thermal superinsulation (TSI) materials such as aerogels (ABs) and vacuum insulated panels (VIPs). While ABs provide exceptional thermal performance with minimal thickness, their internal application is limited by space constraints, making external insulation more advantageous for avoiding space reduction and protecting building elements from corrosion. Thermal bridges can be mitigated by combining VIPs with materials like expanded polystyrene (EPS), enabling heat loss reductions of up to 90%. However, the high cost of these materials, such as silica aerogel, poses a challenge, despite projections showing the annual market budget for silica aerogel surpassing $10 billion by 2027. Future research will focus on eco-friendly solutions and integrating TSI materials with conventional building components to enhance energy efficiency and reduce costs. Insulation continues to gain popularity due to its significant impact on the environment and high energy costs [38-39].

### 1.5. Energy-efficient building design

The European Union's energy strategy mandates that new buildings achieve "nearly zero" energy consumption by 2020. Achieving these goals requires research into cost-effective technologies that reduce energy usage without compromising daylight availability or thermal comfort. One such technology is vacuum glazing, which offers a high level of thermal insulation while maintaining good optical transmittance. This makes it an ideal solution for reducing heat loss without sacrificing natural daylight, contributing to both energy efficiency and indoor comfort. Vacuum glazing has become a promising solution in building design due to its impressive thermal insulation properties and ability to transmit visible light, making it an ideal choice for reducing energy consumption while maintaining natural daylight. A comprehensive review of vacuum glazing technology by Cuce and Cuce [40] highlights its evolution and future prospects, covering both experimental and theoretical studies. It has been found that vacuum glazing can achieve a reduced overall heat transfer coefficient of up to 0.20 $W/m^2K$ when integrated with low-emissivity coatings. This contributes to significant reductions in energy consumption and greenhouse gas emissions. Additionally, vacuum glazing products are assessed in terms of several performance parameters, such as visible light transmittance and solar heat gain coefficient, which further demonstrate their potential as an energy-efficient solution. In terms of retrofit solutions, thin film coatings, known for their control over solar radiation and visible light, show promise when applied to glazed areas. When combined with vacuum glazing, these technologies can optimize window performance, enhancing thermal insulation while maximizing natural light intake [41]. Recent studies have emphasized the importance of accurate U-value assessments for window systems, noting that thermal bridges and edge effects can impact the actual performance of glazing products. Therefore, vacuum glazing combined with advanced thin film technologies represents a valuable approach to enhancing building energy efficiency and reducing environmental impact [42].

While windows provide natural light, they can also contribute to discomfort and heat loss. Ghisi et al. [43] and Suvorova et al. [44] examined the influence of factors such as orientation, window size, and room geometry on energy consumption for lighting, cooling, and heating in offices across various climate zones in USA. Ghisi et al. [43] developed a method for estimating energy savings by integrating daylight into lighting systems, using the Ideal Window Area concept. Their research, conducted in Leeds and Florianopolis, showed potential energy savings of 10.8% to 44.0% for 5000 lux of exterior illumination. Lee et al. [45] investigated the impact of window-to-wall ratios, orientation, U-values, g-values, and optical transmittance on optimizing window designs in offices across five of Asia’s most common climate regions Manila, Taipei, Shanghai, Seoul and Sapporo. Loutzenhiser et al. [46] suggest strategies to reduce the window-to-wall ratio while maximizing daylight in buildings. They recommend using low-emissivity glass and gas-filled cavities to reduce heat gain while still maximizing daylight. However, these strategies may not be as effective in cooling-dominated buildings with high interior heat loads. The energy-saving potential of daylighting is particularly notable in cooling-dominated structures. Motuziene et al. [47] focused on window-to-wall ratios, window orientation, and glazing types to evaluate energy usage in office buildings in Lithuania's cool climate. They found that the most energy efficient window-to-wall ratios (WWR) for the south, east and west oriented façade are 20%.

Persson et al. [48] found that in Sweden's passive homes, the size of windows no longer plays a major role in reducing heating energy demand, emphasizing that cooling need in summer is the primary concern in well-insulated homes.

Recent interest has resurfaced in the indoor thermal environment and the potential non-visual benefits of natural daylight in residential buildings, as highlighted by Mardaljevic et al. [49]. Paridari et al. [50] describe "Active Houses," which are designed to optimize natural lighting and provide pleasant views while maintaining low energy usage and a favorable indoor temperature without negatively affecting the environment. As part of the Model Home 2020 project, Alliance et al. [51] designed "Home for Life" in Denmark to maximize livability, using passive solar and ventilation cooling strategies such as natural cross-ventilation and roof windows to maintain a favorable indoor thermal environment. Foldbjerg et al. [52] found that these solar control strategies effectively maintain comfortable indoor conditions while minimizing energy consumption.

This study addresses the gap in understanding the combined effects of insulation, reflective coatings, and renewable energy systems on achieving net-zero energy in extreme climates like Baghdad. Utilizing advanced simulation tools (HAP and TRACE 700), the research provides reliable insights into cost-effective strategies for reducing heating and cooling loads in residential buildings. By integrating passive and active energy measures, the study offers a holistic approach to minimizing energy consumption and environmental impact. While reliant on simulation data, it sets a foundation for future validation and serves as a blueprint for sustainable building practices in similar climates.

## 2. Problem Description and Governing Equations

This study addresses the energy efficiency and optimization challenges in achieving a net-zero energy building in the specific context of a residential building in Baghdad (Figure 1), where climate conditions result in substantial thermal loads, particularly during summer. The primary focus is on evaluating the impact of exterior insulation and paint layers on the thermal performance of the building. The overall aim is to reduce the building's heating and cooling demands through passive and active energy solutions, including the integration of solar energy systems and optimized building design.

Baghdad's hot summers and relatively cold winters result in high energy consumption for cooling and heating. The problem becomes more critical when considering the urban population growth and the increasing demand for energy in the region. Traditional energy sources lead to high carbon emissions, contributing to environmental degradation and climate change. Thus, transitioning to net-zero energy buildings (NZEB) can help reduce dependency on fossil fuels, lower energy costs, and mitigate environmental impact.

This study uses a combination of passive measures (e.g., improved insulation, energy-efficient coatings) and renewable energy integration to optimize the building's energy profile. Advanced software simulations, including the Hourly Analysis Program (HAP) and TRACE 700, were used to analyze various scenarios, comparing insulation effectiveness, paint reflectivity, and the performance of solar energy systems. The results of this analysis could provide a roadmap for the future design of energy-efficient buildings in similar climates.


Figure 1. Building in Baghdad (case study) [53]

## 2.1. The Hourly Analysis Program (HAP)

The Iraqi refrigeration blog is an online platform for professionals and stakeholders in the refrigeration, cooling, and Heating, Ventilation, and Air Conditioning (HVAC) systems industry in Iraq. It provides a comprehensive resource on refrigeration technology, energy efficiency, sustainability, regulations, and best practices. The blog aims to foster a deeper understanding of the intricacies involved in designing, installing, operating, and maintaining refrigeration and cooling systems across various sectors. It bridges the gap between theory and practice in the refrigeration industry, facilitating continuous learning and professional development. The blog contributes to improved system design, enhanced energy efficiency, and the advancement of the refrigeration sector in Iraq. The Carrier's Hourly Analysis Program (HAP) is a computer tool that assists engineers in designing HVAC systems for commercial buildings. It estimates design loads, determines airflow rates, sizes cooling and heating coils, air circulation fans, and chillers and boilers (Figure 2).

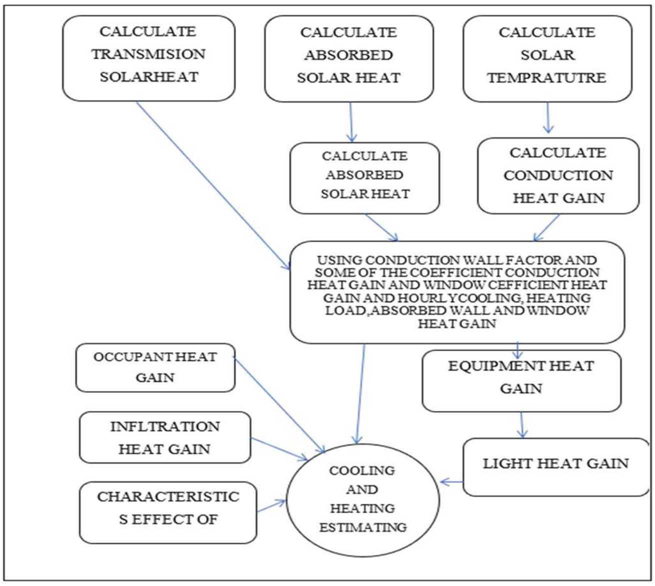


Figure 2. Flow chart HAP software

## 2.2. Hourly thermal load analysis and transfer function

The purpose of calculating load is to determine peak heating and cooling loads which used to size and select equipment and these calculations dependent on:

- Room conditions
- Occupancy
- Building construction
- Location

Factors Effecting Human Comfort

- Temperature
- Humidity
- Air speed

General Practice Comfort Limits [54]

- Air temperature maintained between (20˚C–26˚C)
- Summer: (23˚C–26˚C) 50% RH Max 60% RH
- Winter: (20˚C–23˚C) Min 35% RH
- (3˚C) maximum head-to-foot temperature gradient
- Air Speed in occupied zone: 50 fpm (0.254 m/s) cooling, 30 fpm (0.15 m/s) heating

Heating Load– Heat Loss

Envelope Heat Loss

1. Walls
2. Floor
3. Windows
4. Roof

Heating Load Equation

$$q_{\text{wall}} = q_{\text{window}} = q_{\text{roof}} = Area \cdot U \cdot \Delta T \tag{1}$$

$$q_{\text{floor}} = Perimeter \cdot F \cdot \Delta T \tag{2}$$

$$q_{\text{total}} = q_{\text{wal l}} + q_{\text{window}} + q_{\text{roof}} + q_{\text{floor}} \tag{3}$$

$q = Load$

Unit : BTU /h (Watts)

$U = U$-value as calculated based on material properties

Unit: BTU/(h· ft$^2$·°F) {W/(m$^2$·°C)}

$Fp$ = Heat loss coefficient of slab floor construction

Unit: BTU/(h·ft$^2$·°F) {W/(m$^2$·°C)}

$\Delta T$ = Temperature difference between indoors and outdoors

Determined using ASHRAE published weather tables [52].

Cooling Heat Gain

Internal Heat Gain

1. People
2. Equipment
3. Lights

Envelope Heat Gain

Conductive

1. Walls
2. Floor
3. Windows
4. Roof

Solar

1. Windows

Cooling Load Equations

$$q_{\text{wall}} = U \cdot A \cdot CLTD_{\text{wall}} \tag{4}$$

$CLTD_{\text{wall}}$ depends on: construction (mass), orientation, latitude, time, $\Delta t$

$$q_{\text{roof}} = U \cdot A \cdot CLTD_{\text{roof}} \tag{5}$$

$CLTD_{\text{roof}}$ depends on: construction (mass), time, $\Delta t$

$$q_{\text{window\_cond}} = U \cdot A \cdot CLTD_{\text{window}} \tag{6}$$

$CLTD_{\text{window\_cond}}$ depends on: construction, time, $\Delta t$

$$q_{\text{window\_solar}} = U \cdot SC \cdot SHGF \tag{7}$$

$SHGF$ : Solar heat gain factor

$SHGF$ depends on: orientation, time

$$q_{\text{light}} = 3.412\ W \cdot F_{\text{ul}} \cdot F_{\text{sa}} \cdot N \tag{8}$$

$W$ = wattage
$F_{\text{ul}}$ = lighting use factor (ratio of wattage in use)
$F_{\text{sa}}$ = lighting allowance factor ( ballast + lamp)
$N$ = number of light

$$q_{\text{total}} = q_{\text{envlope}} + q_{\text{people}} + q_{\text{equipment}} + q_{\text{light}} \tag{9}$$

($q$ people, $q$ equipment) depends on number of people and equipment [52].

## 3. Results and Discussion

### 3.1. Validation with Trane Traces 700 software

HAP and TRACE 700 are essential tools in building energy analysis and HVAC engineering. They help engineers evaluate the energy efficiency of HVAC systems and their impact on energy usage. Both programs simulate and examine HVAC systems on an hourly basis, allowing for understanding of system functions over time. They also assist in sizing HVAC equipment for comfort and efficiency. HAP and TRACE 700 can calculate heating and cooling loads for a building using variables like environment, building orientation, insulation, and occupancy. They can determine if a building meets local building rules, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1, LEED, and other energy codes and standards. Engineers can create energy models of buildings using HAP and TRACE 700, which can be used to compare different design options and energy-saving strategies. Both programs offer customizable options, allowing users to specify HVAC system configurations and operational schedules suited to their project needs. They can also determine how energy-saving solutions, such as variable-speed drives, high-efficiency machinery, and control methods, affect a building's energy usage and operating expenses. The choice between HAP and TRACE 700 depends on factors like user preference, project needs, and software familiarity within an engineering organization. Engineers and designers can choose the tool that best suits their individual requirements and project goals.

In a validation process, HAP was compared with Trane TRACE 700 software, a similar tool used for energy analysis and load calculations (Table 1-2) in building HVAC systems. The validation involved simulating a building with light paint and insulation using both programs, applying the same parameters. The results showed a difference of less than 5% between the two software tools, a margin considered acceptable for engineering purposes. This confirms that both HAP and Trane TRACE 700 provide reliable and consistent results for such analyses.

Table 1. Terminal unit sizing data – cooling

| Zone name | Cooling coil load (kW) | | Sensible coil load (kW) | | Zone (L/(s.m^2)) | |
|---|---|---|---|---|---|---|
| | (HAP) | (Trace 700) | (HAP) | (Trace 700) | (HAP) | (Trace 700) |
| Reception | 3.1 | 3.0 | 2.8 | 2.7 | 7.3 | 7.0 |
| Living room | 3.0 | 2.9 | 2.8 | 2.7 | 13.9 | 13.3 |
| Kitchen | 2.6 | 2.5 | 2.4 | 2.3 | 9.9 | 9.5 |
| Bed room | 2.1 | 2.0 | 2.0 | 1.9 | 7.5 | 7.2 |
| Bed room 1 | 1.6 | 1.5 | 1.5 | 1.4 | 8.6 | 8.3 |
| Bed room 2 | 2.2 | 2.1 | 2.0 | 1.9 | 8.0 | 7.6 |
| Master bed room | 3.0 | 2.9 | 2.8 | 2.7 | 8.3 | 8.0 |

Table 2. Terminal unit sizing data - heating, fan, ventilation

| Zone Name | Heating coil load (kW) | | Fan design airflow (L/s) | | OA vent design air flow (L/s) | |
|---|---|---|---|---|---|---|
| | (HAP) | (Trace 700) | (HAP) | (Trace 700) | (HAP) | (Trace 700) |
| Reception | 1.9 | 1.8 | 188.0 | 180.5 | 23.0 | 22.1 |
| Living room | 1.6 | 1.5 | 208.0 | 199.7 | 20.0 | 19.2 |
| Kitchen | 1.5 | 1.4 | 176.0 | 169.0 | 14.0 | 13.4 |
| Bed room | 1.3 | 1.2 | 143.0 | 137.3 | 11.0 | 10.6 |
| Bed room 1 | 1.1 | 1.1 | 112.0 | 107.5 | 6.0 | 5.8 |
| Bed room 2 | 1.3 | 1.2 | 151.0 | 145.0 | 11.0 | 10.6 |
| Master bed room | 2.0 | 1.9 | 212.0 | 203.5 | 13.0 | 12.5 |

### 3.2. Cooling load

The Heating, Ventilation, and Air Conditioning (HVAC) program is crucial in designing an HVAC system. It estimates the cooling load, which is the amount of heat energy needed to maintain a comfortable temperature in a building. Accurate calculations help in selecting and sizing HVAC equipment, reducing energy usage and costs. HAP data also aids in designing environmentally responsible HVAC systems, reducing greenhouse gas emissions. Engineers and designers use HAP-generated data to select the right cooling equipment, system type, capacity, and energy sources. HAP also helps in predicting long-term maintenance and operational expenses, ensuring the system remains affordable over its life. The HAP program's cooling load calculations enable architects and engineers to create thermally comfortable, environmentally friendly, and sustainable spaces.

Figure 3. shows the comparison between the insulation states or not in the light paint. Where it is noted that the value of the cooling load is reduced to half in the case of insulation, and this indicates its usefulness in using it to reduce the cooling load. In the living room, the value of the cooling load when isolated was 3 kW, but with the absence of the insulation, it rises to 6.8 kW, and this difference is vast and can be benefited It is to improve cooling loads.

Figure 4. shows the effect of the presence of insulation with no insulation on the cooling load using dark paint. The results prove once again the effectiveness of using insulators in reducing the cooling load. In the same living room, the value of the cooling load in the case of insulation was 3 kW, but with the absence of the cooling load, it rises to 7 kW, which is a big difference.

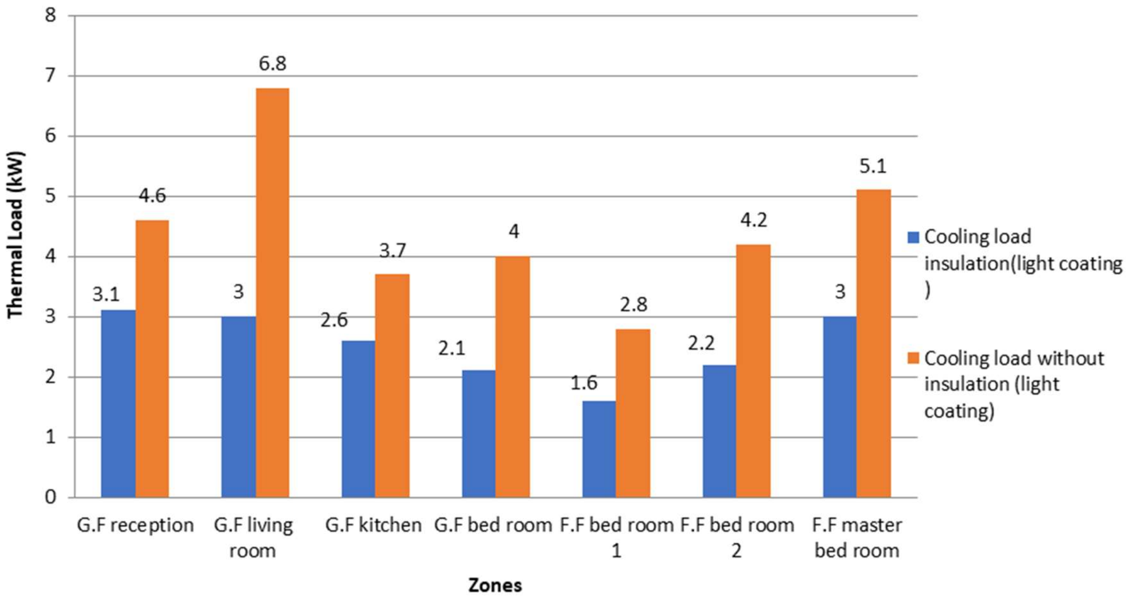


Figure 3. Cooling load insulation vs. cooling load without insulation (light coating)

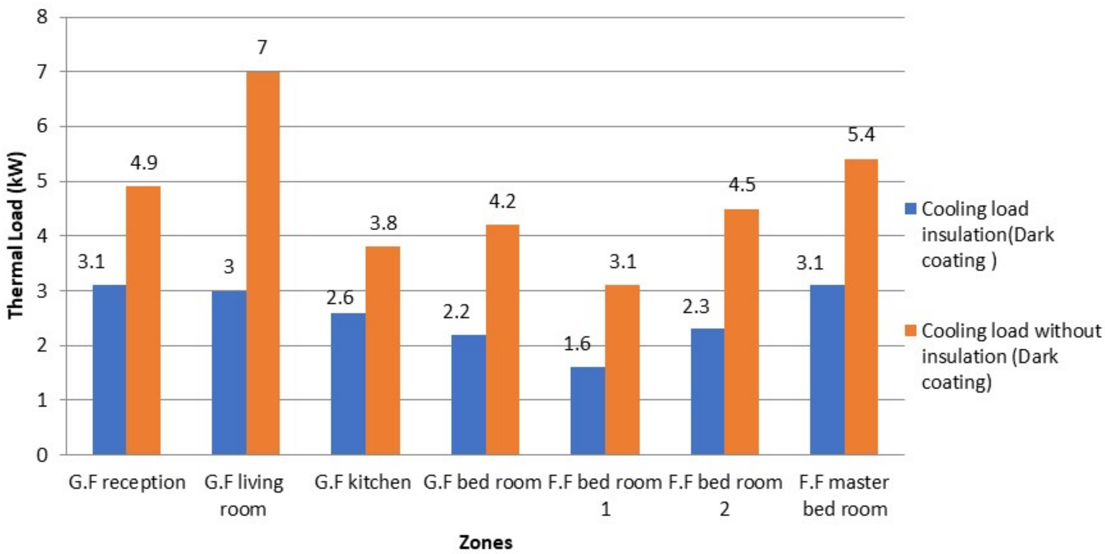


Figure 4. Cooling load with insulation vs. cooling load without insulation (dark coating)

The presence of windows and windows during the used building was many, and therefore the coating areas are few in Figure 1., as the difference between the light and dark coatings decreases, and this is what is noticeable in Figure 5., which shows the difference between the cooling load in the presence of light and dark coatings with an insulating coating, as the difference is non-existent in the living room and its value 3 kW for each floor. The difference increases in the master bedroom, so the value of the cooling load reached 3.1 kW during the dark coating and 3 kW in the light coating.

Figure 6. shows the same concept with regard to the effect of the paint, but in this case, with the absence of an insulator, the effect of changing the paint increased. The difference between the two types of paint in the cooling load reached the largest value in the master bedroom, as it was 5.4 kW in the dark paint and 5.1 kW in the light paint.

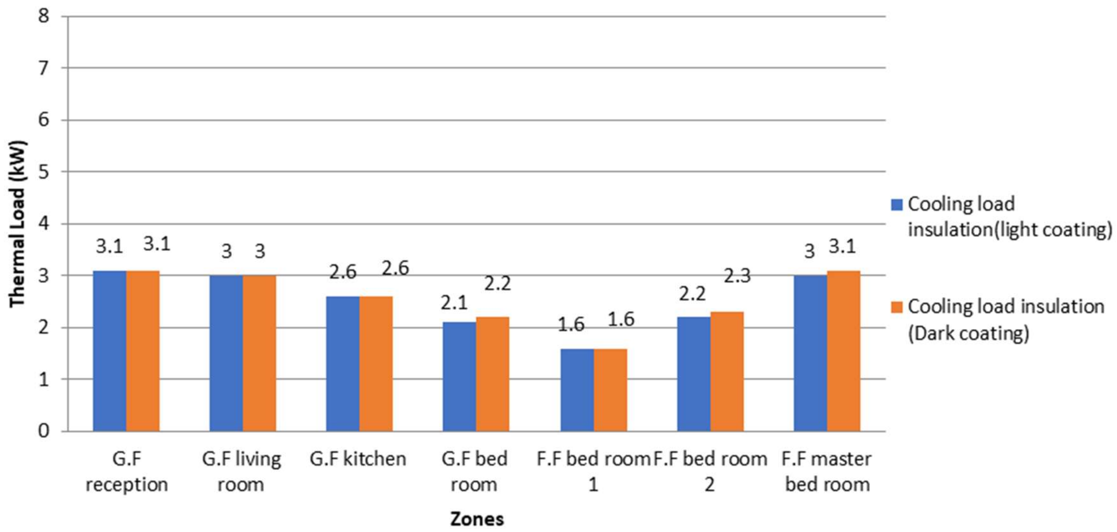


Figure 5. Cooling load insulation (light coating vs. dark coating)

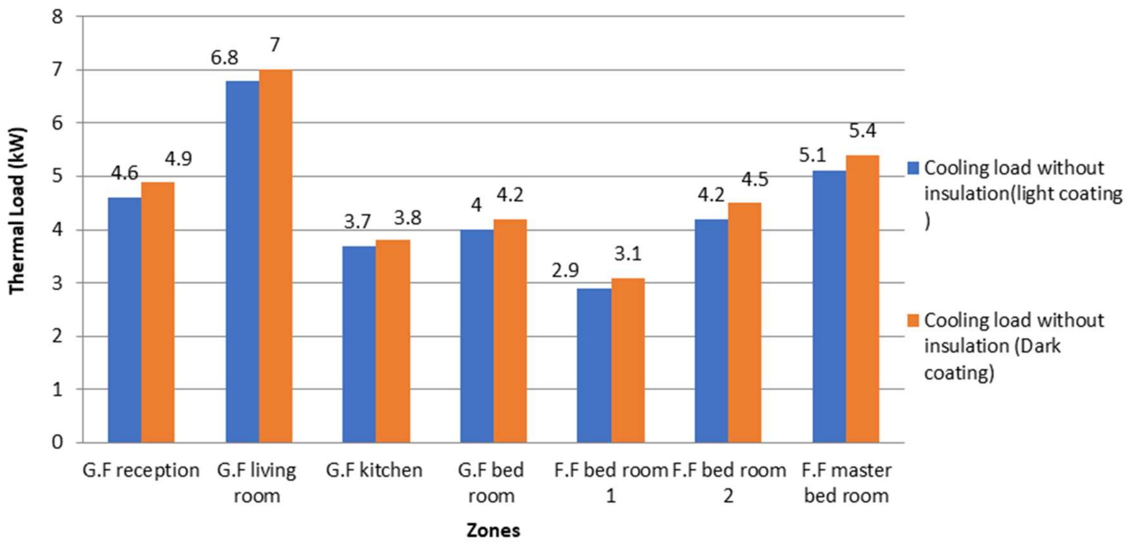


Figure 6. Cooling load without insulation (light coating vs. dark coating)


PRINT ISSN: 2149-4916 E-ISSN: 2149-9373 

### 3.3. Heating load

The heating load of a structure is the thermal energy needed to maintain a building's interior temperature during cold or winter weather. It is crucial in designing and sizing heating systems, as it determines the capacity and effectiveness of heating equipment. The building's insulation, layout, and activities contribute to the heating load. Higher passenger density and heat-generating activities can increase the load. The building's ventilation needs, air leaks, and passive solar heating can also affect the load. The heating load is influenced by occupants' desired indoor temperature, and efficient heating system design aims to satisfy the load while avoiding equipment oversizing.

Figure 7. shows a comparison between cases of insulation or not in light coatings. Where it is noted that the value of the heating load decreases to half in the case of insulation, and this indicates the benefit of using it in reducing the heating load. In the living room, the value of the heating load when isolated was 1.6 kW, but with the absence of the insulation it rises to 3.4 kW, and this difference is vast and can be used to improve heating loads.

Figure 8. shows the effect of the presence of insulation with no insulation on the heating load using dark paint. The results prove once again the effectiveness of using insulators in reducing the heating load. In the same living room, the value of the heating load in the case of insulation was 1.6 kW, but with the absence of the Heating load, it rises to 3.3 kW, which is a big difference.

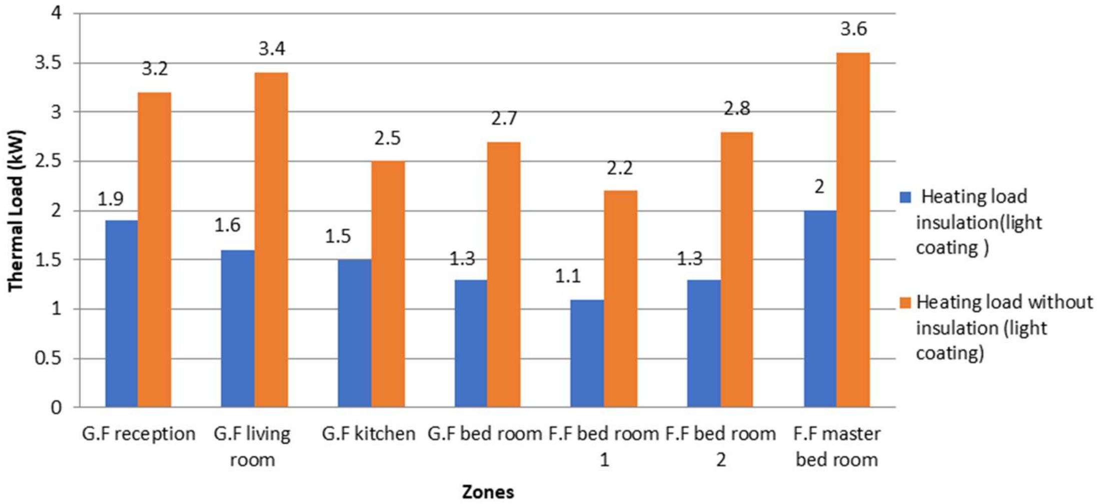


Figure 7. Heating load insulation vs. heating load without insulation (light coating)

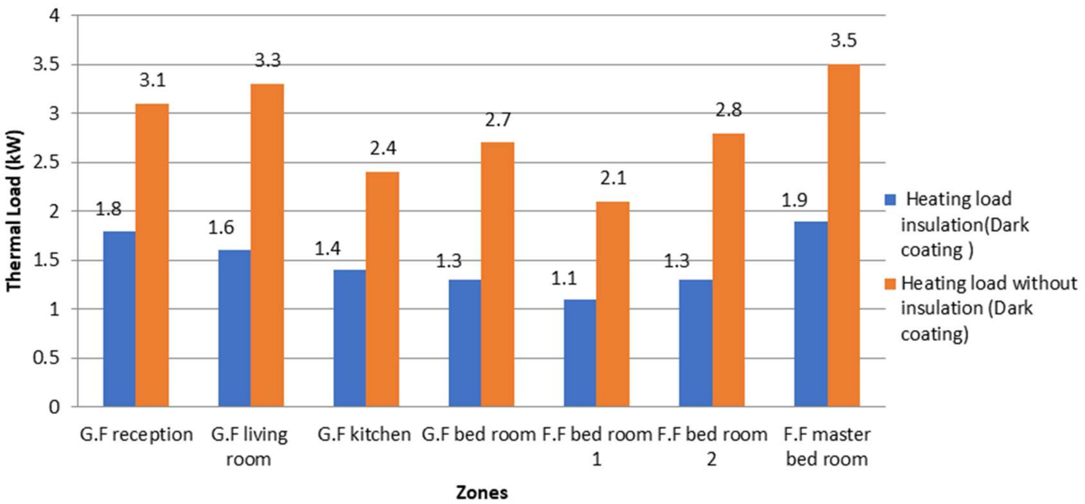


Figure 8. Heating load insulation vs. heating load without insulation (dark coating)



PRINT ISSN: 2149-4916 E-ISSN: 2149-9373 

Figure 9. shows an improvement in reducing the heating load for rooms painted with dark insulated paint compared to rooms painted with light insulated paint, due to the presence of more areas painted with dark paint than windows. Where an improvement is noticed in reducing the heating load in relation to the master bedroom 2, where the heating load in the insulated dark coating is 1.9 kW, while the heating load in the light coating is 2 kW.

Figure 10. shows the same concept with regard to the effect of the paint, but in this case, with the absence of an insulator, the effect of changing the paint increased. The difference between the two types of paint in the heating load reached the largest value in the master bedroom, as it was 3.5 kW in the dark paint and 3.6 kW in the dark paint. light paint.

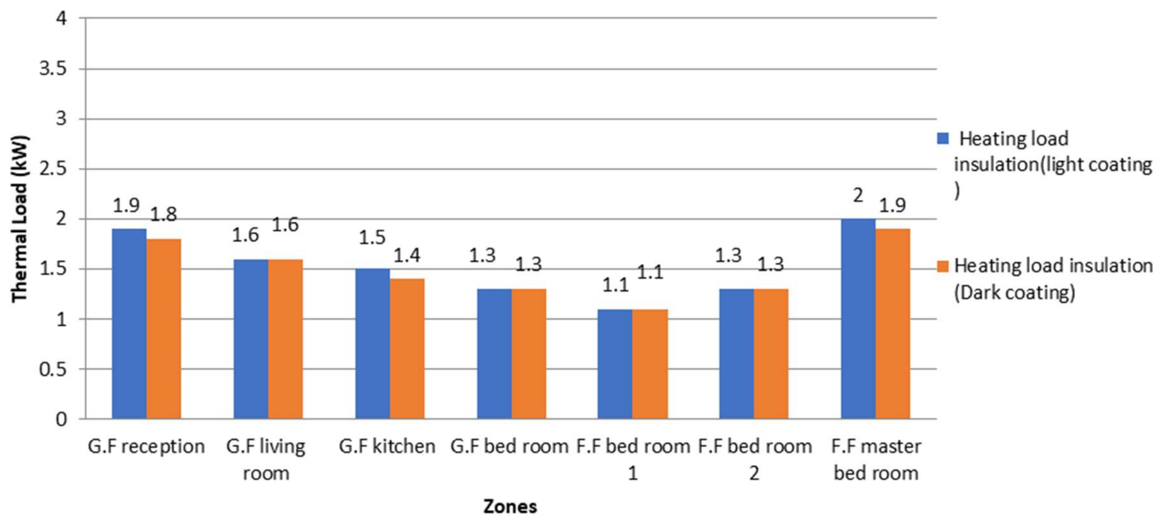

Figure 9. Heating load with insulation (light coating vs. dark coating)

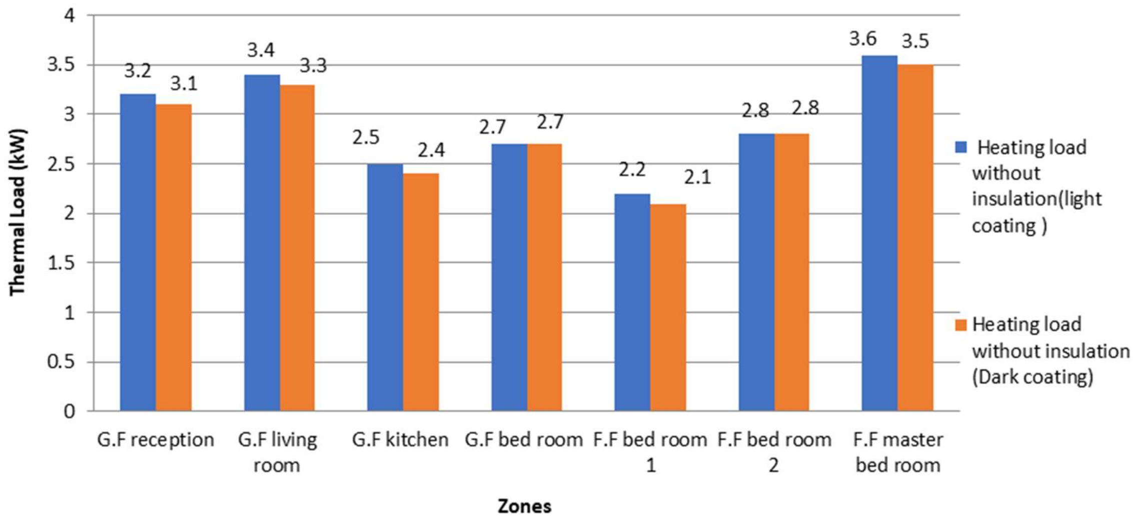

Figure 10. Heating load without insulation (light coating vs. dark coating)

### 3.4. Total heating and cooling loads for each case

After the process of studying thermal loads during different seasons and knowing the amount of energy required to obtain an integrated system that achieves zero energy, work has been done on a solar panel system that feeds three phases capable of operating cooling and heating systems 24 hours a day. Where the electrical model was designed by the Simulink program, the solar panel system was simulated and the voltage was obtained to feed the systems used as in Figure 11.


PRINT ISSN: 2149-4916 E-ISSN: 2149-9373 

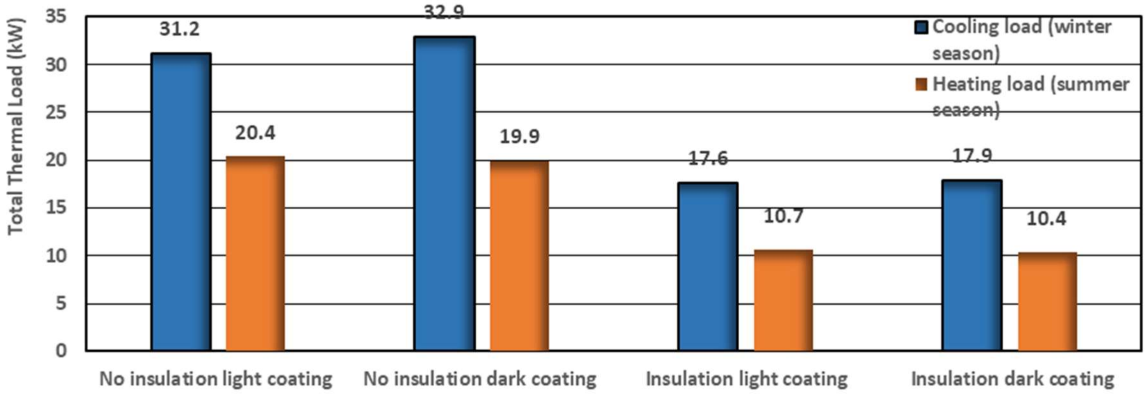


Figure 11. Total heating and cooling load (light coating vs. dark coating)

## 3.5. Zero energy calculation

The Variable Refrigerant Flow (VRF) system's efficiency depends on factors such as insulation, exterior coating, and local climate. Insulation reduces the amount of electricity needed for heating and cooling, while exterior coatings absorb more solar heat. Local climate, humidity, building size, and design also impact the load. Internal heat gain is influenced by heat-generating activities and the number of people inside the structure. The tenants' indoor temperature also affects energy consumption. Proper maintenance, including cleaning filters and coils, is necessary to keep the VRF system running efficiently. Energy modeling or consulting a qualified HVAC engineer can help assess energy requirements accurately. In conclusion, a VRF system's energy requirements for insulation and light coating depend on various factors, including climate and building design (Table 3).

Figure 12 clears the actual need for electrical capacity for (cooling and heating load) in summer and winter seasons for each case, The figure shows that the electrical power required for the insulated cases is much less than the no insulated cases, while the electrical power for the light and dark coating for the two cases(insulating and no insulating)is equal due to the close cooling and heating capacities for the light and dark coating cases therefore the selection of VRF system be similar for light and dark coating for two cases insulating and no insulating.



PRINT ISSN: 2149-4916 E-ISSN: 2149-9373 

Table 3. The amount of electrical energy calculated for the devices in the case of light coating with insulation for cooling load (summer season) and heating load (winter)

| Coating Color | Insulation | Season | (kW) | FF bed room 1 | FF bed room 2 | FF master bed room | GF bed room | GF kitchen | GF living room | GF reception | Power input (W) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Light | With | Winter | Room load | 1,10 | 1,30 | 2,00 | 1,30 | 1,50 | 1,60 | 1,90 | 3660 |
| | | | Heating capacity | 1,80 | 1,80 | 2,50 | 1,80 | 1,80 | 1,80 | 2,50 | |
| | | Summer | Room load | 1,6 | 2,2 | 3,0 | 2,1 | 2,6 | 3,0 | 3,1 | 5940 |
| | | | Cooling capacity | 1,6 | 2,2 | 3,6 | 2,2 | 2,8 | 3,6 | 3,6 | |
| Light | With out | Winter | Room load | 1,10 | 1,30 | 1,90 | 1,30 | 1,40 | 1,60 | 1,80 | 3660 |
| | | | Heating capacity | 1,80 | 1,80 | 2,50 | 1,80 | 1,80 | 1,80 | 2,50 | |
| | | Summer | Room load | 1,60 | 2,30 | 3,00 | 2,20 | 2,60 | 3,00 | 3,10 | 5940 |
| | | | Cooling capacity | 1,60 | 2,20 | 3,60 | 2,20 | 2,80 | 3,60 | 3,60 | |
| Dark | With | Winter | Room load | 2,10 | 2,80 | 3,50 | 2,70 | 2,40 | 3,30 | 3,10 | 5900 |
| | | | Heating capacity | 2,50 | 3,20 | 4,00 | 3,20 | 2,50 | 4,00 | 3,20 | |
| | | Summer | Room load | 3,1 | 4,5 | 5,4 | 4,2 | 3,8 | 7,0 | 4,9 | 9300 |
| | | | Cooling capacity | 3,6 | 4,5 | 5,6 | 4,5 | 4,5 | 7,1 | 5,6 | |
| Dark | With out | Winter | Room load | 2,20 | 2,80 | 3,60 | 2,70 | 2,50 | 3,40 | 3,20 | 5900 |
| | | | Heating capacity | 2,50 | 3,20 | 4,00 | 3,20 | 2,50 | 4,00 | 3,20 | |
| | | Summer | Room load | 2,90 | 4,20 | 5,10 | 4,00 | 3,70 | 6,80 | 4,60 | 9300 |
| | | | Cooling capacity | 3,60 | 4,50 | 5,60 | 4,50 | 4,50 | 7,10 | 5,60 | |

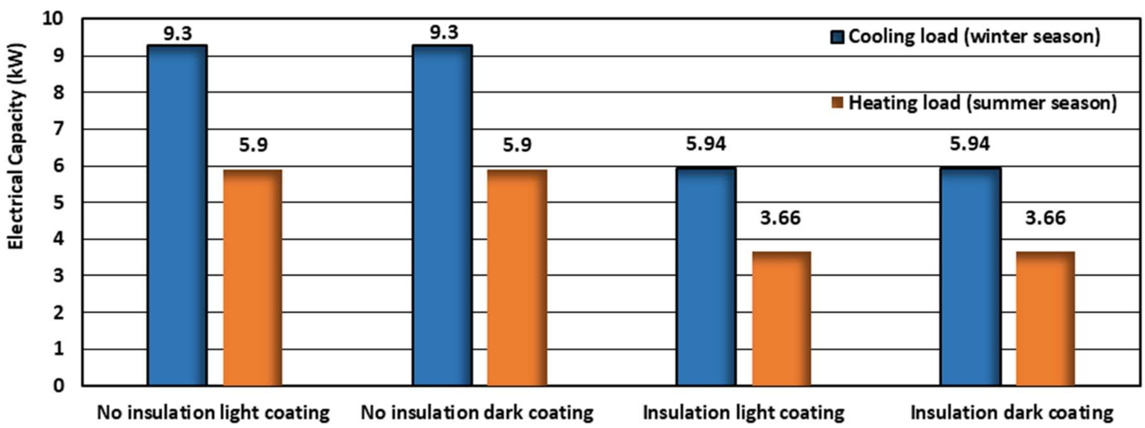


Figure 12. Electrical capacity for (cooling and heating load) in summer and winter seasons

### 3.6. Supplying cooling and heating systems by solar panels

After the process of studying thermal loads during different seasons and knowing the amount of energy required to obtain an integrated system that achieves zero energy, work has been done on a solar panel system that feeds three phases capable of operating cooling and heating systems 24 hours a day. Where the electrical model was designed by the Simulink program, the solar panel system was simulated and the voltage was obtained to feed the systems.

In order to obtain an amount of capacity that can be used for processing and storing in batteries, it is necessary to use twice the solar panels for the energy required for the purpose of supplying cooling and heating systems over a 24-hour period. The values of the energy extracted from the solar panels during the summer were approximately 12 kW, but in the winter, they reached 8.3 kW as in Figure 13.

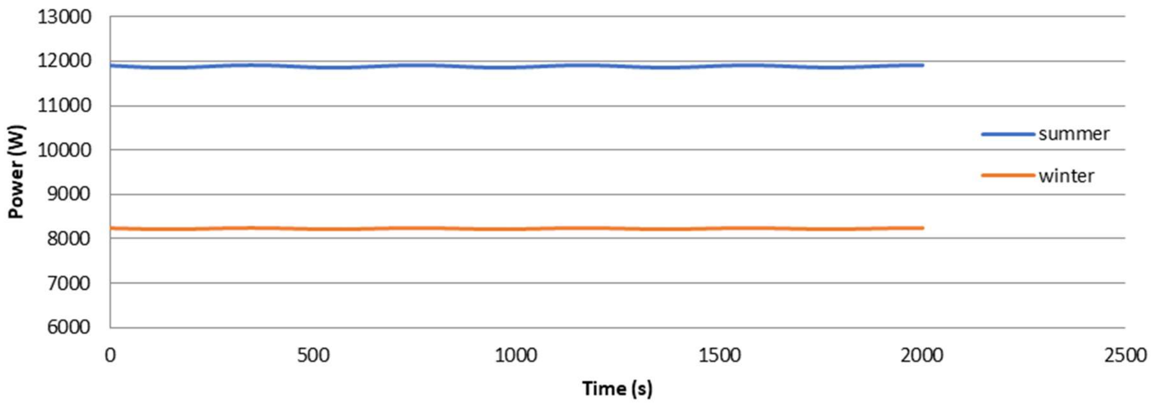


Figure 13. The output power of solar panel system

## 4. Conclusion

This study evaluates the combined impact of insulation, reflective coatings, and renewable energy integration on achieving net-zero energy goals for residential buildings in extreme climates. The results highlight significant improvements in energy efficiency through these measures.

- Insulation reduced cooling loads by approximately 56% in the living room (from 6.8 kW to 3.0 kW) and heating loads by 53% (from 3.4 kW to 1.6 kW).
- For dark coatings, cooling loads increased slightly compared to light coatings, but the effect was minimal. In the master bedroom, the cooling load increased by 3.3% (from 3.0 kW to 3.1 kW) when insulated and by 5.9% (from 5.1 kW to 5.4 kW) when not insulated.
- Heating loads showed a reduction of 5% in the master bedroom for dark coatings compared to light coatings when insulated (from 2.0 kW to 1.9 kW).
- Solar panels generated sufficient energy to power the VRF system, producing 12 kW in summer and 8.3 kW in winter, exceeding the VRF system's requirements of 5.94 kW (summer) and 3.66 kW (winter), with surplus energy stored for later use.
- Validation results showed a less than 5% variance between HAP and TRACE 700 simulation tools, confirming the reliability of findings.

In line with the growing importance of energy efficiency in extreme climates, other studies conducted in Iraq also emphasize the need for sustainable building practices.

- For example, a study focused on the design of sustainable models for residential buildings in North Iraq addresses the significant impact of local climate, building design, and occupant behavior on energy use. It found that residential buildings in North Iraq account for approximately 69% of the total electricity consumed, emphasizing the importance of energy-saving measures. The study utilized mixed research methods and simulations to develop a sustainable model, showing potential energy savings of up to 50% through improved designs and occupancy behavior adjustments [55].
- Additionally, research aimed at providing energy-efficient housing guidelines for architects in Iraq highlights the potential to achieve up to 50% energy reduction in housing units. This study, based on computer simulations of a reference building in Baghdad, identified cost-effective solutions for improving energy efficiency while considering local materials and budgets. The results indicate that

substantial energy savings can be achieved within a reasonable payback period, with some measures providing immediate benefits [56].

The findings of this study offer valuable insights into practical applications that can be implemented in residential buildings to enhance energy efficiency. Homeowners and builders can significantly reduce energy consumption by these strategies not only contribute to environmental sustainability but also provide actionable pathways toward achieving net-zero energy goals in everyday living spaces.

- Insulation remains a cost-effective solution for retrofitting existing buildings, significantly lowering heating and cooling demands and ensuring occupant comfort.
- Solar energy systems demonstrate practical viability, offering a sustainable alternative to traditional energy sources in regions with high solar potential.
- This research provides actionable insights into sustainable building practices, emphasizing the transformative potential of integrating insulation, reflective coatings, and renewable energy systems to achieve net-zero energy goals.

As the demand for sustainable building practices continues to grow, strategic integration of new technologies will play a crucial role in shaping the future of energy-efficient homes.

- Research into advanced insulation materials, coatings, and renewable systems tailored to different climates can further enhance energy efficiency.
- Integrating hybrid photovoltaic-thermal systems or battery storage can improve energy balance and autonomy for residential buildings.
- Policy recommendations could include the widespread adoption of these techniques in urban planning to achieve sustainable, energy-efficient housing.

## Acknowledgment

This article is derived from the thesis with the same title, completed at Karabuk University under the supervision of Assist. Prof. Dr. Mutlu Tekir.

## Conflict of Interest Statement

The authors declare that there is no conflict of interest.

## References

[1] N. Zhou, L. Price, D. Yande, J. Creyts, N. Khanna, D. Fridley, H. Lu, W. Feng, X. Liu, and A. Hasanbeigi, "A roadmap for China to peak carbon dioxide emissions and achieve a 20% share of non-fossil fuels in primary energy by 2030," *Applied Energy*, vol. 239, pp. 793–819, April 2019. doi: 10.1016/j.apenergy.2019.01.154

[2] P. Nejat, F. Jomehzadeh, M. M. Taheri, M. Gohari, and M. Z. A. Majid, "A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries) ," *Renewable And Sustainable Energy Reviews*, vol. 43, pp. 843–862, March 2015. doi: 10.1016/j.rser.2014.11.066

[3] K. Lebling, M. Ge, K. Levin, R. Waite, J. Friedrich, C. Elliott, C. Chan, K. Ross, F. Stolle, and N. Harris, "State of climate action: assessing progress toward 2030 and 2050," *World Resource Institute (WRI)*, ClimateWorks Foundation, Nov. 2020. [Online]. Available: https://www.wri.org/research/state-climate-action-assessing-progress-toward-2030-and-2050. [Accessed: Feb. 21, 2024]

[4] J. Burke, R. Byrnes, and S. Fankhauser, "How to price carbon to reach net-zero emissions in the UK," *Policy Report*, London School Of Economics, London, 2019. [Online]. Available: https://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2019/05/GRI_POLICY-REPORT_How-to-price-carbon-to-reach-net-zero-emissions-in-the-UK.pdf. [Accessed: Feb. 21, 2024]

[5] V. Pandiyarajan, M. C. Pandian, E. Malan, R. Velraj, and R. V. Seeniraj, "Experimental investigation on heat recovery from diesel engine exhaust using finned shell and tube heat exchanger and thermal storage system," *Applied Energy*, vol. 88, no. 1, pp. 77–87, Jan. 2011. doi: 10.1016/j.apenergy.2010.07.023

[6] I. Staffell, D. Brett, N. Brandon, and A. Hawkes, "A review of domestic heat pumps," *Energy & Environmental Science*, vol. 5, no. 11, pp. 9291–9306, Sept. 2012. doi: 10.1039/C2EE22653G

[7] E. Alvur, M. Anaç, P. M. Cuce, and E. Cuce, "The Potential and Challenges of Bim in Enhancing Energy Efficiency in Existing Buildings: A Comprehensive Review," *Sustainable and Clean Buildings*, vol. 1, no. 1, pp. 42-65, 2024. [Online]. Available: https://ojs.wiserpub.com/index.php/scb/article/view/4988. [Accessed: Dec. 23, 2024]

[8] M. Alzara, A. M. Yosri, A. Alruwaili, E. Cuce, S. M. Eldin, and A. Ehab. "Dynamo script and a BIM-based process for measuring embodied carbon in buildings during the design phase," *International Journal of Low-Carbon Technologies*, vol. 18, pp 943-955, June 2023. doi: 10.1093/ijlct/ctad053

[9] J. Amann, A. Wilson, and K. Ackerly, *Consumer Guide to Home Energy Savings-: Save Money, Save the Earth*, 10th Edition, New Society Publishers, Nov. 2012.

[10] C. Liaukus, "Energy efficiency measures to incorporate into remodeling projects," *National Renewable Energy Lab.(NREL)*, Golden, CO (United States), Dec. 2014. [Online]. Available: https://www.nrel.gov/docs/fy15osti/63154.pdf. [Accessed: Feb. 22, 2024]

[11] D. A. Jump, I. S. Walker, and M. P. Modera, "Field Measurements of Efficiency and Duct Effectiveness in Residential Forced Air Distributions Systems," *American Council for an Energy-Efficient Economy*, 1996. [Online]. Available: https://www.aceee.org/files/proceedings/1996/data/papers/SS96_Panel1_Paper15.pdf. [Accessed: Feb. 22, 2024]

[12] M. Deng, P. Li, M. Shan, and X. Yang, "Optimizing supply airflow and its distribution between primary and secondary air in a forced-draft biomass pellet stove," *Environmental Research*, vol. 184, pp. 109301, May 2020. doi: 10.1016/j.envres.2020.109301

[13] Z. Liao, and A. L. Dexter, "The potential for energy saving in heating systems through improving boiler controls," *Energy And Buildings*, vol. 36, no. 3, pp. 261–271, March 2004. doi: 10.1016/j.enbuild.2003.12.006

[14] G. Martinopoulos, K. T. Papakostas, and A. M. Papadopoulos, "A comparative review of heating systems in EU countries, based on efficiency and fuel cost," *Renewable And Sustainable Energy Reviews*, vol. 90, pp. 687–699, July 2018. doi: 10.1016/j.rser.2018.03.060

[15] S. D. Watson, K. J. Lomas, and R. A. Buswell, "Decarbonising domestic heating: What is the peak GB demand?," *Energy Policy*, vol. 126, pp. 533–544, March 2019. doi: 10.1016/j.enpol.2018.11.001

[16] V. Pais-Magalhães, V. Moutinho, and M. Robaina, "Is an ageing population impacting energy use in the European Union? Drivers, lifestyles, and consumption patterns of elderly households," *Energy Research & Social Science*, vol. 85, pp. 102443, March 2022. doi: 10.1016/j.erss.2021.102443

[17] H. W. Sinn, "Buffering volatility: A study on the limits of Germany's energy revolution," *European Economic Review*, vol. 99, pp. 130–150, Oct. 2017. doi: 10.1016/j.euroecorev.2017.05.007

[18] L. Aelenei, D. Aelenei, H. Gonçalves, R. Lollini, E. Musall, A. Scognamiglio, E. Cubi, and M. Noguchi, "Design issues for net zero-energy buildings," *Open House International*, vol. 38, no. 3, pp. 7-14, Sept. 2013. doi: 10.1108/OHI-03-2013-B0002

[17] D. MacKay, *Sustainable Energy-without the Hot Air*, UIT Cambridge, 2009.

[18] J. W. Lee, B. Hawkins, D. M. Day, and D. C. Reicosky, "Sustainability: the capacity of smokeless biomass pyrolysis for energy production, global carbon capture and sequestration," *Energy & Environmental Science*, vol. 3, no. 11, pp. 1695–1705, July 2010. doi: 10.1039/C004561F

[19] H. I. Onovwiona, and V. I. Ugursal, "Residential cogeneration systems: review of the current technology," *Renewable And Sustainable Energy Reviews*, vol. 10, no. 5, pp. 389–431, Oct. 2006. doi: 10.1016/j.rser.2004.07.005

[20] A. J. Perea-Moreno, M. Á. Perea-Moreno, Q. Hernandez-Escobedo, and F. Manzano-Agugliaro, "Towards forest sustainability in Mediterranean countries using biomass as fuel for heating," *Journal Of Cleaner Production*, vol. 156, pp. 624–634, July 2017. doi: 10.1016/j.jclepro.2017.04.091

[21] K. J. Chua, and S. K. Chou, "Energy performance of residential buildings in Singapore," *Energy*, vol. 35, no. 2, pp. 667–678, Feb. 2010. doi: 10.1016/j.energy.2009.10.039

[22] N. Daouas, "A study on optimum insulation thickness in walls and energy savings in Tunisian buildings based on analytical calculation of cooling and heating transmission loads," *Applied Energy*, vol. 88, no. 1, pp. 156–164, Jan. 2011. doi: 10.1016/j.apenergy.2010.07.030

[23] B. Givoni, "Effectiveness of mass and night ventilation in lowering the indoor daytime temperatures. Part I: 1993 experimental periods," *Energy And Buildings*, vol. 28, no. 1, pp. 25–32, Aug. 1998. doi: 10.1016/S0378-7788(97)00056-X

[24] N. Artmann, H. Manz, and P. Heiselberg, "Climatic potential for passive cooling of buildings by night-time ventilation in Europe," *Applied Energy*, vol. 84, no. 2, pp. 187–201, Feb. 2007. doi: 10.1016/j.apenergy.2006.05.004

[25] C. Tian, T. Chen, H. Yang, and T. Chung, "A generalized window energy rating system for typical office buildings," *Solar Energy*, vol. 84, no. 7, pp. 1232–1243, July 2010. doi: 10.1016/j.solener.2010.03.030

[26] S. Boixo, M. Diaz-Vicente, A. Colmenar, and M. A. Castro, "Potential energy savings from cool roofs in Spain and Andalusia," *Energy*, vol. 38, no. 1, pp. 425–438, Feb. 2012. doi: 10.1016/j.energy.2011.11.009

[27] T. C. Cheng, C. H. Cheng, Z. Z. Huang, and G. C. Liao, "Development of an energy-saving module via combination of solar cells and thermoelectric coolers for green building applications," *Energy*, vol. 36, no. 1, pp. 133–140, Jan. 2011. doi: 10.1016/j.energy.2010.10.061

[28] A. Strzalka, N. Alam, E. Duminil, V. Coors, and U. Eicker, "Large scale integration of photovoltaics in cities," *Applied Energy*, vol. 93, pp. 413–421, May 2012. doi: 10.1016/j.apenergy.2011.12.033

[29] A. M. Foley, P. G. Leahy, A. Marvuglia, and E. J. McKeogh, "Current methods and advances in forecasting of wind power generation," *Renewable Energy*, vol. 37, no. 1, pp. 1–8, Jan. 2012. doi: 10.1016/j.renene.2011.05.033

[30] E. Cuce, P. M. Cuce, C. Wood, M. Gillott, and S. Riffat, "Experimental Investigation of Internal Aerogel Insulation Towards Low/Zero Carbon Buildings: A Comprehensive Thermal Analysis for a UK Building," *Sustainable and Clean Buildings*, vol. 1, no.1., pp. 1-22, Feb. 2024. [Online]. Available: https://ojs.wiserpub.com/index.php/scb/article/view/4072. [Accessed: Dec. 23, 2024]

[31] E. Cuce, P. M. Cuce, E. Alvur, Y. N. Yilmaz, S. Saboor, I. Ustabas, E. Linul, and M. Asif, "Experimental performance assessment of a novel insulation plaster as an energy-efficient retrofit solution for external walls: A key building material towards low/zero carbon buildings," *Case Studies in Thermal Engineering*, vol. 49, pp. 103350, Sept. 2023. doi: 10.1016/j.csite.2023.103350

[32] P. M. Cuce, E. Alvur, E. Cuce, S. Alshahrani, C. Prakash, H. Tan, and I. Ustabas, "Unlocking energy efficiency: Experimental investigation of bamboo fibre reinforced briquettes as sustainable solution with enhanced thermal resistance," *Case Studies in Thermal Engineering*, vol. 60, pp. 104680, Aug. 2024. doi: 10.1016/j.csite.2024.104680

[33] P. M. Cuce, E. Cuce, and K. Sudhakar, "A systematic review of thermal insulation performance of hollow bricks as a function of hollow geometry," *International Journal of Ambient Energy*, vol. 43, no. 1, pp. 4406-4415, 2022. doi: 10.1080/01430750.2021.1907619

[34] Z. Azkorra, G. Pérez, J. Coma, L. F. Cabeza, S. Bures, J. E. Álvaro, A. Erkoreka, and M. Urrestarazu, "Evaluation of green walls as a passive acoustic insulation system for buildings," *Applied Acoustics*, vol. 89, pp. 46–56, March 2015. doi: 10.1016/j.apacoust.2014.09.010

[35] M. Shekarchian, M. Moghavvemi, B. Rismanchi, T. M. I. Mahlia, and T. Olofsson, "The cost benefit analysis and potential emission reduction evaluation of applying wall insulation for buildings in Malaysia," *Renewable And Sustainable Energy Reviews*, vol. 16, no. 7, pp. 4708–4718, Sept. 2012. doi: 10.1016/j.rser.2012.04.045

[36] Ö. A. Dombayci, "The environmental impact of optimum insulation thickness for external walls of buildings," *Building And Environment*, vol. 42, no. 11, pp. 3855–3859, Nov. 2007. doi: 10.1016/j.buildenv.2006.10.054

[37] A. Bolattürk, "Optimum insulation thicknesses for building walls with respect to cooling and heating degree-hours in the warmest zone of Turkey," *Building And Environment*, vol. 43, no. 6, pp. 1055–1064, June 2008. doi: 10.1016/j.buildenv.2007.02.014

[38] S. Christopher, M. P. Vikram, C. Bakli, A. K. Thakur, Y. Ma, Z. Ma, H. Xu, P. M. Cuce, E. Cuce, and P. Singh, "Renewable energy potential towards attainment of net-zero energy buildings status–a critical review," *Journal of Cleaner Production*, vol. 405, pp. 136942, June 2023. doi: 10.1016/j.jclepro.2023.136942

[39] P. M. Cüce, E. Cüce, and E. Alvur, "Internal or external thermal superinsulation towards low/zero carbon buildings: A critical report," *Gazi Mühendislik Bilimleri Dergisi*, vol. 9, no. 3, pp. 435-442, Dec. 2023. doi: 10.30855/gmbd.07050777

[40] E. Cuce and P. M. Cuce, "Vacuum glazing for highly insulating windows: Recent developments and future prospects," *Renewable and Sustainable Energy Reviews*, vol. 54, pp. 1345-1357, Feb. 2016. doi: 10.1016/j.rser.2015.10.134

[41] E. Cuce, P. M. Cuce, and S. Riffat, "Thin film coated windows towards low/zero carbon buildings: Adaptive control of solar, thermal, and optical parameters," *Sustainable Energy Technologies and Assessments*, vol. 46, pp. 101257, Aug. 2021. doi: 10.1016/j.seta.2021.101257

[42] E. Cuce, "Accurate and reliable U-value assessment of argon-filled double glazed windows: A numerical and experimental investigation," *Energy and Buildings*, vol. 171, pp. 100-106, July 2018. doi: 10.1016/j.enbuild.2018.04.036

[43] E. Ghisi and J. A. Tinker, "An ideal window area concept for energy efficient integration of daylight and artificial light in buildings," *Building And Environment*, vol. 40, no. 1, pp. 51–61, Jan. 2005. doi: 10.1016/j.buildenv.2004.04.004

[44] I. Susorova, M. Tabibzadeh, A. Rahman, H. L. Clack, and M. Elnimeiri, "The effect of geometry factors on fenestration energy performance and energy savings in office buildings," *Energy And Buildings*, vol. 57, pp. 6–13, Feb. 2013. doi: 10.1016/j.enbuild.2012.10.035

[45] J. W. Lee, H. J. Jung, J. Y. Park, J. B. Lee, and Y. Yoon, "Optimization of building window system in Asian regions by analyzing solar heat gain and daylighting elements," *Renewable Energy*, vol. 50, pp. 522–531, Feb. 2013. doi: 10.1016/j.renene.2012.07.029

[46] P. G. Loutzenhiser, G. M. Maxwell, and H. Manz, "An empirical validation of the daylighting algorithms and associated interactions in building energy simulation programs using various shading devices and windows," *Energy*, vol. 32, no. 10, pp. 1855–1870, Oct. 2007. doi: 10.1016/j.energy.2007.02.005

[47] V. Motuziene and E. S. Juodis, "Simulation based complex energy assessment of office building fenestration," *Journal Of Civil Engineering And Management*, vol. 16, no. 3, pp. 345–351, Sept. 2010. doi: 10.3846/jcem.2010.39

[48] M. L. Persson, A. Roos, and M. Wall, "Influence of window size on the energy balance of low energy houses," *Energy And Buildings*, vol. 38, no. 3, pp. 181–188, March 2006. doi: 10.1016/j.enbuild.2005.05.006

[49] J. Mardaljevic, M. Andersen, N. Roy, and J. Christoffersen, "A framework for predicting the non-visual effects of daylight–Part II: The simulation model," *Lighting Research & Technology*, vol. 46, no. 4, pp. 388–406, Aug. 2014. doi: 10.1177/1477153513491873

[50] K. Paridari, A. Parisio, H. Sandberg, and K. H. Johansson, "Energy and CO 2 efficient scheduling of smart appliances in active houses equipped with batteries," *IEEE International Conference on Automation Science and Engineering, CASE 2014*, New Taipei, Taiwan, Aug. 18-22, 2014, S.L. Chen, C.C. Lan, J. Li, D. Popa, Eds. New Jersey: IEEE Xplore, 2014, pp. 632-639. doi: 10.1109/CoASE.2014.6899394

[51] A. H. Alliance, "Active House–The Specifications for Residential Buildings," *activehouse.info*. Brussels: Active House Alliance, Jan. 31, 2013. [Online]. Available: https://www.activehouse.info/wp-content/uploads/2020/01/Guidelines_ActiveHouse_III_2020_Spreads.pdf. [Accessed: Dec. 25, 2024]

[52] P. Foldbjerg and T. Asmussen, "Using ventilative cooling and solar shading to achieve good thermal environment in a Danish Active House," *rehva.eu*. The REHVA European HVAC Journal, vol. 50, no. 3, pp. 36–42, March 2013. [Online]. Available: https://www.rehva.eu/rehva-journal/chapter/using-ventilative-cooling-and-solar-shading-to-achieve-good-thermal-environment-in-a-danish-active-house. [Accessed: Feb. 23, 2024]

[53] “Baghdad Boulevard Project,” [Online]. Available: https://g.co/kgs/Ct8WJpJ. [Accessed: Oct. 1, 2024]

[54] M. S. Kam, "25.5 deg C and human comfort," *emsd.gov.hk*. Report energy and efficiency office, the government of Hong Kong special administrative region, 2004. [Online]. Available: https://www.emsd.gov.hk/filemanager/conferencepaper/en/upload/22/HKIE_Environment_Annual_Seminar_Paper_25.5_deg_C_and_Human_Comfort.pdf. [Accessed: Dec. 23, 2024]

[55] M. Aldoski, D. Haji, and H. Sevinc, "A Sustainable Residential Building Model in North Iraq by Considering Occupant Behaviour, Sociocultural Needs, and the Impact on Energy Use," *Sustainability*, vol. 16, no. 9, pp. 3651, April 2024. doi: 10.3390/su16093651

[56] U. Dietrich, S. Rashid, and W. Willkomm, "Guidelines for Low-Cost, Energy-Efficient House in Iraq," *Journal of Civil Engineering and Architecture*, vol. 8, no. 12, pp. 1473-1481, Dec. 2014. doi: 10.17265/1934-7359/2014.12.001