



**Department of Construction Material and Technology
Budapest University of Technology and Economics**

**A comparative hygrothermal analysis of a family house in Hungary
and India enhancing energy efficiency and indoor comfort**

**Salman Ali
Neptun Code: YKG6EV**

Consultants: Dr. Nagy Balázs, Szagri Dóra

**Department of Construction Material and Technology
Faculty of Civil Engineering
Budapest University of Technology and Economics
2022-2023**

Table of Contents

List of Figures	
List of Tables	
Common Abbreviation Used in this Paper	
Abstract in Hungarian	
Abstract in English	
1. Introduction	1
2. Building and Material Properties.....	6
2.1 Layer order of the building constructed based on the traditional method.....	8
2.2 Layer order of the building constructed based on the standard method.....	8
2.3 Exterior and Interior Wall.....	11
2.4 Floor	12
2.5 Slab.....	12
2.6 Windows and Doors	13
2.7 Material Properties	14
2.7.1 Concrete, w/c 0.5	16
2.7.2 Concrete Screed Top Layer.....	16
2.7.3 Cement Plaster	17
2.7.4 Interior Plaster (Gypsum Plaster).....	17
2.7.5 Mortar (historical): Lime + Cocciopesto (crushed bricks)	18
2.7.6 Solid Brick	18
2.7.7 Extruded Polystyrene Insulation (XPS).....	19
2.7.8 Expanded Polystyrene Insulation (EPS)	19
2.7.9 Mineral Wool	20
2.7.10 Wienerberger Solid Brick	20
3. Dynamic hygrothermal simulation	21
3.1 Weather Description	21
3.2 Boundary Conditions.....	24

3.3	Wufi Plus software	24
4.	Result and Discussion.....	26
4.1	Un-insulated Building	26
4.2	Insulated Buildings.....	31
		34
4.3	Comparison of two insulated and Uninsulated building in two different geographic location.	36
4.1	Analysis of building after increasing infiltration ACH (1/h) from 0.1 to 0.4	41
5.	Conclusion	43
6.	Acknowledgement	45
7.	Reference	46

List of Figures

Figure 1: Per Capita Energy Consumption (Source: Central Electricity Authority)[6]	2
Figure 2:Energy consumption of buildings relative to other sectors, 2022 [7]	3
Figure 3: 3D model of Building with transparent view	6
Figure 4: Flat Roof Properties Figure 5: Floor Slab Properties	7
Figure 6: Exterior Wall Parameters Figure 7: Windows Parameters	7
Figure 8: Internal Loads/occupancy.....	8
<i>Figure 10:Standard Brick with frog</i>	12
Figure 9:Exterior wall cross-section (Source: Google)	12
Figure 11: Brick Slab with reinforcement[17]	13
Figure 12: Reinforced Cement Concrete[18].....	13
Figure 13: Concrete – Left: Thermal Conductivity and Temperature Right: RH and Water Content.....	16
Figure 14: Concrete Screed - (Left) Temperature and Thermal conductivity (Right) RH and water content.....	16
Figure 15: Concrete Screed - (a) Thermal Conductivity and Temperature (b) Diffusion resistance factor (c) Normalized water content and liquid transport coefficient (d) RH and Water Content	16
Figure 16:Cement Plaster - (Left) Temperature and Thermal conductivity (Right) RH and water content.....	17
Figure 17: Interior Gypsum Plaster- (Left) Temperature and Thermal (Right) RH and water content.....	17
Figure 18: Crushed Brick- (left) Thermal Conductivity and Temperature (Right) RH and Water Content	18
Figure 19:Solid Brick- (left) Thermal Conductivity and Temperature (Right) RH and Water Content.....	18
Figure 20: XPS- (left) Thermal Conductivity and Temperature (Right) RH and Water Content	19
Figure 21: EPS - (a) Temperature and Thermal conductivity (b) Diffusion factor (c) Normalised water content and liquid transport coefficient (d) RH and water content	19
Figure 22: EPS- (left) Thermal Conductivity and Temperature (Right) RH and Water Content	19

Figure 23:Mineral Wool- Top Left: Thermal conductivity Top Right: Temperature and Thermal Conductivity Bottom Left: Normalised water content and liquid transport coefficient Bottom Right: RH and water content.....	20
Figure 24: Wienerberger Solid brick Top Left: Thermal conductivity Top Right: Temperature and Thermal Conductivity Bottom Left: Normalised water content and liquid transport coefficient Bottom Right: RH and water content.	20
Figure 25: Temperature and Relative Humidity Bareilly.....	21
Figure 26: Bareilly solar radiation and wind-driven rain directional distributions (Taken from Wufi Plus Climate analysis).....	22
Figure 27: Budapest Solar radiation and wind driven rain directional distributions (Taken from Wufi Climate Analysis).....	23
Figure 28: Comprehensive Energy Fluctuations in Non-Insulated Structures	26
Figure 29: Energy Fluctuations by Component in Non-Insulated Structures.....	28
Figure 30: Hourly representation of heating and cooling in uninsulated building (left: Bareilly Right: Budapest)	28
Figure 31:Monthly energy consumption due to heating and cooling in an Uninsulated family house (left: Bareilly, right: Budapest).....	29
Figure 32: Overheating climate of uninsulated buildings, Bareilly	29
Figure 33: Monthly heat flows in an uninsulated family house (left: Bareilly right: Budapest)	30
Figure 34: Hourly heat flows in an uninsulated family house (left: Bareilly and right: Budapest)	30
Figure 35:Total energy gain/loss in an insulated family house.....	31
Figure 36: Energy gain/loss by a component of insulated building.....	33
Figure 37:Quality of indoor environment of uninsulated buildings (Bareilly).....	33
Figure 38: Quality of indoor environment of insulated buildings (Bareilly).....	33
Figure 39: Representation of hourly heating and cooling in an insulated family house (Left: Bareilly and Right: Budapest).....	34
Figure 40: Monthly energy representation of cooling and heating in the insulated family house (left: Bareilly, right: Budapest)	34
Figure 41: Hourly heat flows in an insulated building (left: Bareilly, right: Budapest)	35
Figure 42: Monthly heat flows in an insulated family house (left: Bareilly, right: Budapest)	35
Figur43: Overheating climate	36

Figure 44: Quality of indoor environment of Budapest (Top: After Insulation Bottom: Before Insulation)	37
Figure 45: Consumption of Energy for Heating and Cooling of Un-Insulated Structures	38
Figure 46: Consumption of Energy for Heating and Cooling of Insulated Structures	38
Figure 47: Quantifying Total Energy Fluctuations in Uninsulated and Insulated Buildings in the Bareilly Context	39
Figure 48: Quantifying Total Energy Fluctuations in Uninsulated and Insulated Buildings in the Budapest Context	39
Figure 49: Examining the Differences in the Budapest Zone Between Un-Insulated and Insulated Buildings	40
Figure 50: Examining the Differences in the Bareilly Zone Between Un-Insulated and Insulated Buildings	40
Figure 51: Indoor thermal environment and Air Quality of Budapest (top: ACH 0.4 1/h and bottom: 0.1 1/h).....	41
Figure 52: Indoor thermal environment and Air Quality of Bareilly (top: ACH 0.1 1/h and bottom: 0.4 1/h).....	41
Figure 53: Heating and Cooling demand after changing infiltration air rate.....	42
Figure 54: Total Energy gain and loss by component of building after changing Air infiltration rate.....	42

List of Tables

Table 1: Layer orders of traditional method-based building.....	9
Table 2: Layer orders of standard method-based building.....	10
Table 3: Materials Properties.....	14
Table 4: Materials Properties.....	15
Table 5: Weather Data	21
Table 6: Energy gain/loss by a component of uninsulated building	27
Table 7: Energy gain/loss by a component of insulated building.....	32
Table 8: Thermal transmittance and thermal resistance value.....	37

Abbreviations / Nomenclature:

ACC	Autoclaved Aerated Concrete	HVAC	Heat Ventilation and Air Conditioning
RCC	Reinforced Cement Concrete	IAQ	Indoor Air Quality
		PRC	Pew Research Center
EGD	European Green Deal	IEA	International Energy Agency
EU	European Union		
CO ₂	Carbon Dioxide	DPC	Damp Proof Course
EPS	Expanded Polystyrene	MSL	Mean Sea level
XPS	Extruded Polystyrene	PCC	Plain Cement Concrete
RH	Relative humidity	TC	Thermal Conductivity
3D	Three Dimensional	LED	Light Emitting Diode

Symbol	Name	Unit
c	Specific heat capacity	J/kgK
ρ	Density	kg/m ³
λ	Thermal Conductivity	W/mK
T	Temperature	⁰ C or K
U	Thermal transmittance	W/m ² K
R	Thermal Resistance	m ² K/W
a	Area	m ²
	Thermal conductivity supplement	[%/M.-%]
	Energy	kWh

Abstract in Hungarian

Egy magyarországi és indiai családi ház összehasonlító higrotermikus elemzése az energiahatékonyság és a beltéri komfort fokozása érdekében

Kulcsszavak: Dinamikus szimuláció, épületenergetika, beltéri környezet, energiahatékonyság, hőszigetelés

Az épületek energiafogyasztását nagymértékben befolyásolják a beltéri környezetre (hőmérséklet, szellőzés és világítás), valamint az épület üzemeltetésére és kialakítására vonatkozó kritériumok. Az építőipari ágazat döntő szerepet játszik az EU energia- és környezetvédelmi céljainak elérésében, mivel az összes energia mintegy 1/3-át a fűtésre, hűtésre, szellőztetésre és a páratartalom szabályozására használják fel, hogy kielégítsék a lakók hőkomfort iránti igényét. Ugyanakkor az energiahatékony épületek javítanák a lakosok életminőségét és csökkentenék az energiaszegénységet. A változó éghajlatra és a COVID-19 járvány miatt a távmunka irányába történő jelentős elmozdulásra reagálva egyre nagyobb szükség van a kényelmet, egészséget és energiahatékonyságot biztosító beltéri környezetre.

A kutatás egy modellezett egyszintes családi ház dinamikus szimulációjának átfogó elemzését mutatja be, különös tekintettel a különböző hőszigetelésekre és építőanyagokra, amely két különböző földrajzi régióban került elhelyezésre: Magyarországon és Indiában. A vizsgálat az EN 15026:2023 szabvány szerinti dinamikus szimulációt alapján készült egy családi ház energetikai teljesítményének és higrotermikus viselkedésének értékelésére változó éghajlati körülmények között, figyelembe véve az óránkénti időjárási adatokat és a lakókra jellemző belső terhelést is.

A kutatásban Wufi Plus szoftverben létrehozott 3D-s épületmodell került alkalmazásra, amely a magában foglalta a családi ház változó kialakítású épületszerkezeti és épülettechnikai rendszereinek modellezését is. A tanulmány vizsgálja, hogy ezek a paraméterek hogyan befolyásolják a beltéri komfortot, a nedvességkezelést és az energiahatékonyságot.

Jelen kutatás értékes meglátásokkal járul hozzá az építőipar számára a hőszigetelés és az építőanyagok felhasználásával kapcsolatban az energiahatékonyság és a beltéri komfort optimalizálása érdekében. Az eredmények alátámasztják a fenntartható építési gyakorlatok és az energiatakarékosság szükségességét a globális éghajlati célok elérése érdekében.

Abstract in English

Keywords: Dynamic Building Simulation, Building Energetics, Indoor environment, Energy efficiency, energy performance, thermal insulation

Energy consumption of buildings is greatly affected by the criteria used for the indoor environment (temperature, ventilation, and lighting) as well as the operation and design of the building. The building sector plays a crucial role in attaining the EU energy and environmental goals, since around 1/3rd of the total energy is used to heat, cool, ventilate, and control humidity to meet the thermal comfort demand of the occupants. At the same time, energy-efficient buildings would improve the quality of inhabitants' lives and reduce energy poverty. In response to the changing climate and a significant shift towards remote work due to the COVID-19 pandemic, there is an elevated need for indoor environments that offer comfort, health, and energy efficiency.

This research paper presents a comprehensive study of the dynamic simulation of a modeled one-story family house situated in two distinct geographical regions: Hungary and India specifically focusing on the various thermal insulation and building materials. The investigation includes dynamic simulation according to EN 15026:2023 standard to evaluate a family house's energy performance and hygrothermal performance under varying climatic conditions, considering hourly weather data and occupancy-specific internal load.

The research methodology involves a 3D Building model created within Wufi Plus software for the representation of family houses based on traditional methods and standard engineering structures, incorporating architectural and structural aspects, as well as mechanical HVAC systems. It explores how these parameters influence indoor thermal performance, moisture management, and energy efficiency.

This research contributes valuable insights into the construction industry on using insulation and construction building materials to optimize energy efficiency and indoor climate control. The findings support the need for sustainable building practices and energy conservation to meet global climate goals.

1. Introduction

In contemporary times, the proliferation of high-rise buildings is a global phenomenon, driven by increasing urbanization that attracts a significant portion of the population to urban areas. Over the past few decades, there has been a discernible shift in climatic patterns, marked by a rise in global temperatures. This climatic transformation poses a heating risk within buildings, disrupting our daily lives by causing thermal discomfort. According to a study by the Pew Research Center (PRC) in the USA, in the wake of COVID-19, approximately 60% of employees have opted for remote work, emphasizing the importance of creating comfortable and healthy indoor climates to minimize distractions during work [1].

Ensuring good building services and maintaining a constant temperature are imperative for promoting a comfortable lifestyle and fostering mental well-being. Indoor moisture management plays a crucial role in the overall thermal performance of buildings, influencing Indoor Air Quality (IAQ) and energy efficiency. Low relative humidity (RH) levels inside buildings can pose health risks such as skin dryness, irritation of mucous membranes, and eye discomfort [2]. Conversely, elevated RH levels can lead to significant moisture-related issues for both the building envelope and the indoor environment. Previous literature highlights that mold development initiates when relative humidity reaches the range of 80-95% [3], depending on factors such as material composition, temperature, and exposure duration.

Research by Berglund and Cain indicates that air freshness and acceptability perception decrease with rising temperature and humidity. Relative humidity levels exceeding 65% are associated with judgments of unacceptable air quality. These findings underscore the importance of effective indoor climate management in mitigating health risks, optimizing building performance, and enhancing overall well-being in the face of changing climatic conditions [4].

The primary objective of the European Green Deal (EGD) is to achieve climate neutrality in Europe by the year 2050. Recent observations indicate that the construction sector significantly contributes to environmental burdens, necessitating substantial changes in the industry. The environmental impact of buildings varies based on factors such as heating and cooling demands, electricity usage, and the characteristics of building occupants. A more efficient building design translates to a lesser environmental impact, with the choice of building materials playing a pivotal role. In the case of high-rise buildings, the emission of embodied

CO₂ ranges from 27% to 58%, depending on the composition mix, as highlighted by Fischer et al. in 2022 [5] .

Every country has established building energy codes and standards with the aim of enhancing energy conservation and efficiency in the built environment, aligning with the goals set forth in the Paris Agreement. The dynamic shifts in weather patterns result in temperature fluctuations, impacting the comfort levels within our homes. The evolving indoor climate gives rise to new challenges related to moisture management, the longevity of building materials, user comfort, health considerations, and overall energy efficiency. In the pursuit of internal comfort, many households' resorts to the use of mechanical devices for cooling and heating. However, these conventional methods are neither environmentally friendly nor energy efficient. This reliance on mechanical systems poses additional challenges in the quest for sustainable and efficient solutions in the built environment.

Typically, these mechanical devices operate on electricity, contributing significantly to high energy consumption. India, ranking as the world's third-largest producer and consumer of electricity, boasts an installed capacity of 344 GW. According to the Central Electricity Authority's 2017 report (Figure 1), India's per-capita electricity consumption surged from 631.4 kWh in 2005-06 to 1075 kWh in 2015-16. The World Bank reported a per-capita electricity consumption of 1181 kWh in India for 2019. Despite these figures, the demand for electricity continues to rise steadily, driven by urbanization and advancements in modern technology.

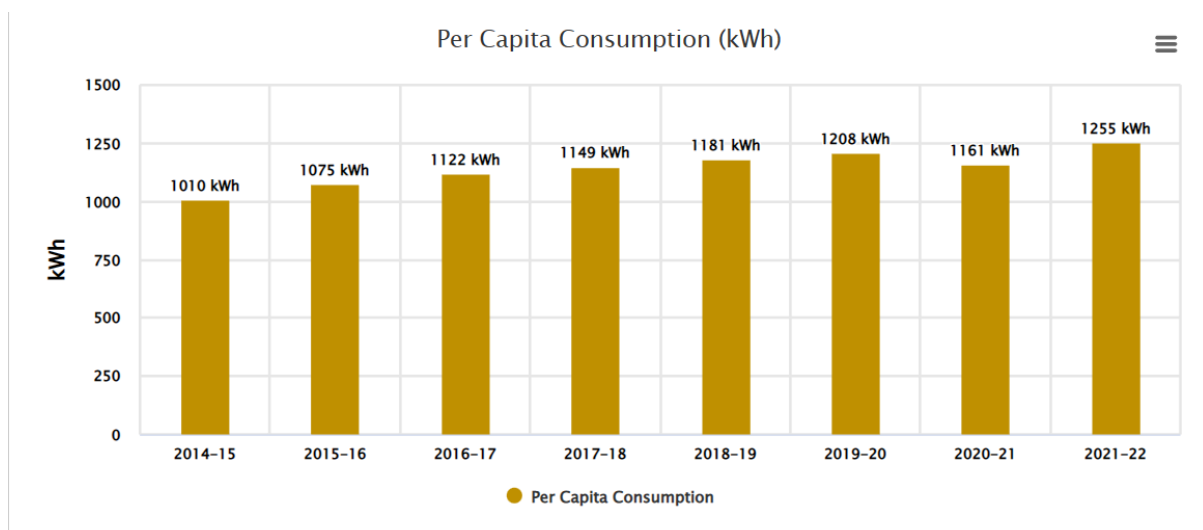


Figure 1: Per Capita Energy Consumption (Source: Central Electricity Authority)[6]

The building sector, encompassing residential, industrial, commercial, and public structures, stands as a primary consumer of energy. This energy consumption spans both electricity and

other sources like natural gas and oil for heating purposes. The International Energy Agency (IEA)[7] highlights that the building and construction industry is anticipated to account for about 35% of global energy demand, closely linked to infrastructure development materials such as cement, steel, and aluminum. Moreover, this sector is responsible for 33% of waste generation, arising from both the dismantling of structures and new construction projects. Figure-2 illustrates the breakdown of global energy consumption, with 20.96% allocated to residential, 8.76% to non-residential, 3.97% to the Building Construction Industry, and 3.33% to the other construction industry. This underscores the substantial impact of the building sector on global energy dynamics and waste generation.

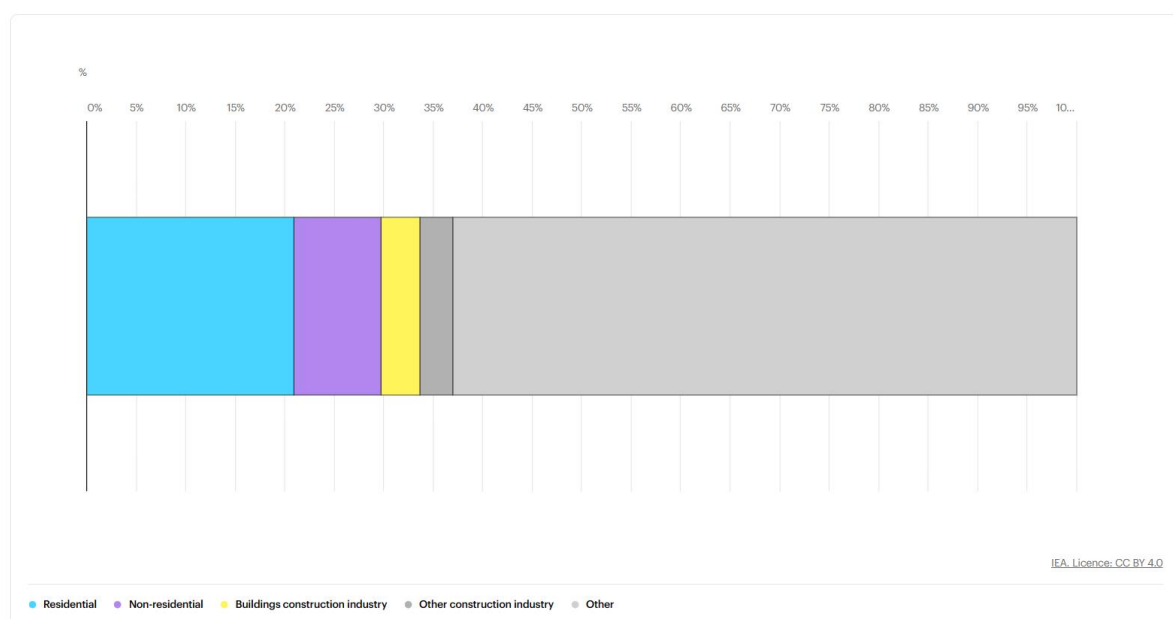


Figure 2:Energy consumption of buildings relative to other sectors, 2022 [7]

Global construction is on the rise due to population growth and urbanization, leading to increased energy demand, waste generation, and greenhouse gas emissions. Stringent regulations in the building and construction industry are being implemented to curb energy usage. It is crucial to raise awareness among local citizens about the benefits of insulated buildings. Conversely, the utilization of insulation and sustainable materials in buildings and industries proves to be an effective strategy to reduce energy consumption, aligning with the criteria for energy certificate requirements in the pursuit of a sustainable world.

The adoption of thermal insulation in building envelopes commenced in the 1970s, as highlighted by Papadopoulos in 2016 [8]. Additionally, Pinto and Da Graça's research in 2018 revealed that the application of thermal insulation and airtightness led to a significant reduction

of 77% and 59% in gas demand for high-rise buildings and townhouses, respectively[9]. These findings underscore the importance of sustainable practices in the construction industry to mitigate the environmental impact and promote energy efficiency. In 2017, India contributed a total of 2344.2 million metric tons of CO₂, representing 7% of the world's total emissions and ranking as the third-highest emitter after China and the USA[10]. Committed to the Paris Agreement, India aims to reduce greenhouse gas emission intensity by 33-35% by 2030. Projections from the National Urban Information System (NUIA) estimate that by 2050, approximately 70% of the population will reside in urban areas, necessitating extensive infrastructure development. To meet this demand, India plans to construct around 800 million square meters of residential and commercial buildings annually until 2050.

This research utilizes dynamic simulation through Wufi Plus software to thoroughly investigate the energy performance and hygrothermal dynamics of a one-story family home. Concentrating on Hungary and India, the study explores how energy consumption, thermal comfort, and indoor air quality are influenced by thermal insulation and building materials, considering the distinct climatic conditions of each region. Employing 3D models that encompass both traditional and standard structures, along with mechanical HVAC systems and architectural nuances, the research closely examines the interactions among these elements. It contributes valuable insights into the impact of various parameters on indoor thermal performance, moisture management, and overall energy efficiency. The role of EN 15251:2006 in this research is pivotal, as it provides guidelines and criteria for assessing indoor environmental factors such as temperature, air quality, and lighting. By establishing a baseline for indoor environmental conditions, this standard enables researchers to evaluate and compare the energy performance of diverse buildings. This standardized framework proves advantageous in designing buildings with a focus on energy efficiency and indoor comfort, particularly within the context of sustainable architecture and energy-efficient building designs[11].

Dóra Szagri and Balázs Nagy found that incorporating additional insulation led to a remarkable 55% decrease in energy consumption in the insulated house. However, residents are required to adapt their behavior, particularly regarding ventilation, to counteract elevated humidity levels in well-insulated structures. The researchers also identified a potential 10% fluctuation in heating energy consumption based on different user behavior parameters[12].

One study revealed that after renovations, more than 66% of participants reported consistently elevated temperatures on upper floors. The research also identified a significant rise in the frequency and duration of summer heatwaves in Europe, attributed to climate change. The implementation of an optimized model, which combines high air change rates and effective shading, showcased a remarkable reduction of 50–75% in overheated hours. The study focused on energy-related retrofits, specifically targeting doors, windows, and heating systems, and observed their implementation in a considerable number of homes. Nighttime ventilation emerged as a pivotal element in mitigating overheating, with higher ventilation rates yielding more substantial benefits. Strategies commonly employed to combat heat encompass shading solutions, LED lighting, and modifications to daily routines [13]. The research carried out by Balasz Nagy and Szagri Dora, they found the discrepancies in the result between calculation and simulations, emphasizing the importance of considering three dimensional thermal bridges in analysis of the industrial house based on Hungarian and Austrian regulations. The paper examines the benefits of whole surface ground insulation, demonstrating that it can lead to a 10% reduction in heating energy consumption[14].

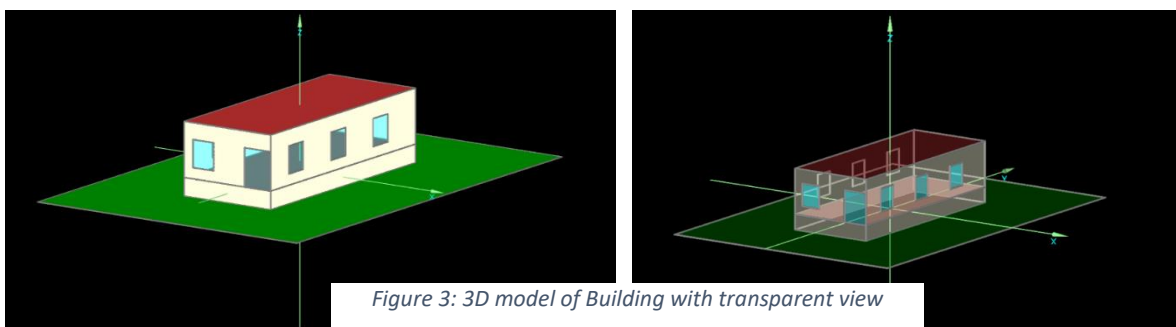
The investigation delves into effective strategies for energy-efficient multi-storey residential buildings across diverse Indian climates. It highlights the considerable energy consumption for cooling and ventilation in these structures, emphasizing the need for designs that prioritize both thermal comfort and energy efficiency. Central strategies involve minimizing solar heat gains, improving insulation in roofs and walls, and optimizing ventilation. Simulations conducted on projects in Indore, Chennai, and Rajkot reveal a potential reduction of 4-7°C in peak temperatures through these approaches. The study suggests tailoring strategies to specific locations and advocates for the incorporation of codes, akin to those in Singapore, to govern building envelope performance. These insights offer valuable contributions to literature focused on sustainable building practices in India's residential sector[15].

Previously, various researchers have conducted numerous studies on different aspects, yet there remains a gap in the literature concerning a comparative analysis of the climatic conditions in Bareilly and Budapest, specifically examining the impact of insulation on two distinct types of buildings. This research places a primary emphasis on evaluating the energy consumption patterns of insulated and non-insulated buildings across these contrasting climatic zones. By delving into this comparative study, it seeks to contribute valuable scientific insights into the energy dynamics of buildings under diverse climatic influences in both Bareilly and Budapest. Moreover, the study explores the global implications of building practices on energy

conservation goals, emphasizing Wufi Plus as a potent tool for professionals in the field. Given the pressing need for resilient, energy-efficient living spaces on a global scale, this research offers actionable insights for sustainable building practices. The comparative analysis involving traditional and standard building methods in Bareilly and Budapest, combined with material evaluations, enriches the understanding of optimizing energy efficiency in construction practices, providing valuable guidance for the transition towards sustainable built environments.

2. Building and Material Properties

India, being a vast country with diverse climatic conditions across its four zones, showcases a variety of construction practices. In rural areas, homes are often constructed using locally available materials such as mud, bamboo, and clay tiles. Conversely, urban residential buildings typically employ reinforced concrete, steel, glass, and bricks, which are common for both family houses and high-rise structures. Although the use of energy-efficient materials is not widespread currently, there is an increasing focus on developing net-zero energy buildings for the future. Policies are being formulated to encourage sustainable building practices among citizens. This research is carried out as a comparative study of energy usage and loss through hygrothermal dynamic simulation of a whole building of one story using different building materials including insulation or without insulation to analyze and calculate the energy efficiency. This study will also focus on the effect of insulation material on the construction industry and energy efficiency. The model created in Wufi mainly focuses on the components primarily responsible for the building's energy consumption, namely the exterior wall, floor, and slab. They play a crucial role in heating, cooling, and ventilation. The model of the exterior wall and flat roof is designed according to the traditional method and standard published by



the Bureau of Energy Efficiency of India[16] and European norms for Budapest. The climatic conditions of both cities are completely different; therefore, we analyze the same model in both geographic climates and see the influence on the energy consumption and internal air quality of the building. The air circulation changes 50% in every hour. The internal minimum

temperature is set 18°C and maximum 27°C and RH 45-50% and maximum reaches 100% in both cases.

General			Assembly	Surface	Initial conditions	Numerics	Report: data & results
Name Floor Slab							
Type/Attachment							
Type	Opaque						
Inner side	Zone 1: Simulated zone						
Outer side	Attached zone 1: Unheated cellar						
Data							
Area [m²]	60						
Inclination [°]	180						
Orientation	Horizontal (100 %)						
Perimeter [m]	34						
Parameters							
Rsi [m²K/W]	0.17						
Rse [m²K/W]	0.17						
Thermal resistance [m²K/W]	4.11						
U [W/m²K]	0.2247						
Other data							
Setting	Setting way	Value					
Height above ground [m]	User defined						

Figure 4: Flat Roof Properties

General			Assembly	Surface	Initial conditions	Numerics	Report: data & results
Name Flat Roof							
Type/Attachment							
Type	Opaque						
Inner side	Zone 1: Simulated zone						
Outer side	Outer air						
Data							
Area [m²]	60						
Inclination [°]	0						
Orientation	Horizontal (100 %)						
Perimeter [m]	34						
Parameters							
Rsi [m²K/W]	0.1						
Rse [m²K/W]	0.04						
Thermal resistance [m²K/W]	3.969						
U [W/m²K]	0.2433						
Other data							
Setting	Setting way	Value					
Height above ground [m]	User defined						

Figure 5: Floor Slab Properties

General			Assembly	Surface	Initial conditions	Numerics	Report: data & results
Name Exterior Wall							
Type/Attachment							
Type	Opaque						
Inner side	Zone 1: Simulated zone						
Outer side	Outer air						
Data							
Area [m²]	15 / 86.25						
Inclination [°]	90						
Orientation	S (12 %), E (35 %), W (35 %), N (17 %)						
Perimeter [m]	16						
Parameters							
Rsi [m²K/W]	0.13						
Rse [m²K/W]	0.04						
Thermal resistance [m²K/W]	4.188						
U [W/m²K]	0.2294						
Other data							
Setting	Setting way	Value					
Height above ground [m]	User defined						

Figure 6: Exterior Wall Parameters

General			Window parameters	Surface	Solar protection	Report: data & results
Name Window						
Type/Attachment						
Type	Transparent					
Inner side	Zone 1: Simulated zone					
Outer side	Outer air					
Data						
Area [m²]	1.8 / 5.4					
Inclination [°]	90					
Orientation	W (100 %)					
Perimeter [m]	5.4					
Parameters						
Rsi [m²K/W]	0.13					
Rse [m²K/W]	0.04					
Uw-mounted [W/m²K]	2.87					
Frame factor [-]	0.7					
U-value frame [W/m²K]						
Other data						
Setting	Setting way	Value				
Height above ground [m]	User defined					

Figure 7: Windows Parameters

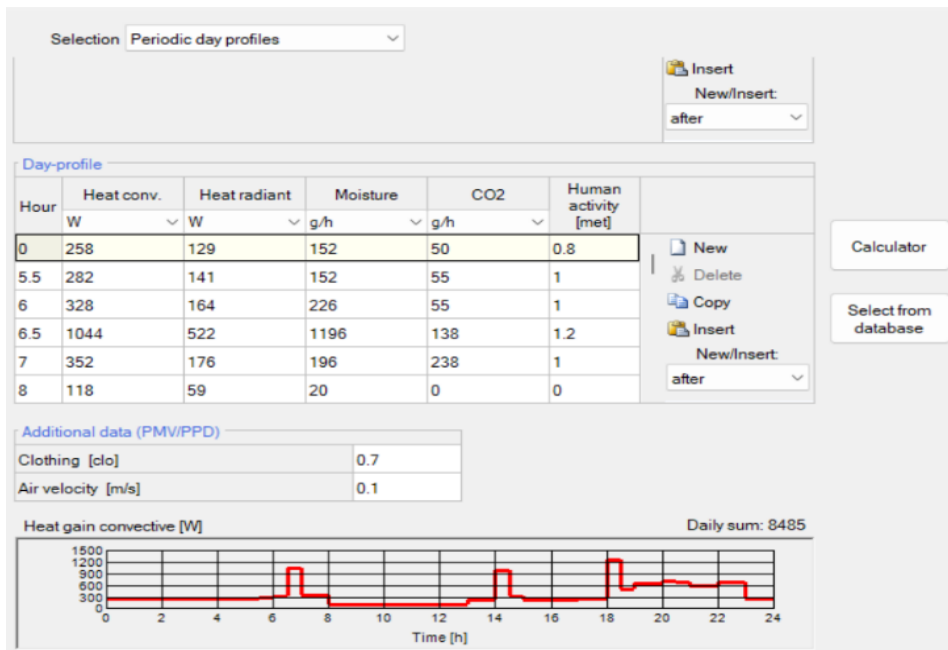


Figure 8: Internal Loads/occupancy

2.1 Layer order of the building constructed based on the traditional method.

We constructed two models for increased comfort in this study, one based on the old technique and the other on the standard layers presented in the previous research which was adopted for standards. The layer pattern I've shown here is based on my observations as well as observations from the construction site in various spots throughout the city. In India, insulation is not usually employed in these types of construction, whereas insulation is used in every building in Hungary. So, we're investigating what would happen if we built these structures in Hungary. We did not use the highlighted layers in the present model since they are relatively thin layers with no data in the Wufi database. The structure was built in the traditional manner consisting of 6 different cases due to the material explained in Table 1.

2.2 Layer order of the building constructed based on the standard method.

Table 2 describes six possibilities for the model developed using the standard layer order. In this situation, insulation is required to achieve thermal comfort inside the building while also minimizing energy usage in both cities Bareilly and Budapest. Case 1a, Case 2a, Case 3a, Case 4a, Case 5a, and Case 6a all have the same floor layers. In this case study, we constructed two types of roof slabs: one to be utilized and one for non-utilization. Although we employed three distinct materials for the outer wall: solid brick, ACC block, and Porotherm.

Table 1: Layer orders of traditional method-based building.

Layer Orders - Traditional Method (Material from Outside to Inside)			
	Exterior wall	Floor	Roof Slab
Case 1	1.5 cm Plaster 23 cm Solid brick 1.5 cm Plaster	1.5 cm Indian Sandstone 5 cm Concrete Screed 15 cm RCC 1 cm Sand	4 cm Concrete Screed 11 cm Brick 1 lyr PE 1.5 cm Plaster 0.6 cm Gypsum Plaster 1 lyr Finishing Paint
Case 2	0.6 cm Gypsum Plaster 1 lyr Finishing Paint	15 cm Crushed Brick Earth Base	1 cm Concrete Screed top layer 12 cm RCC Slab 1.5 cm Plaster 0.6 cm Gypsum Plaster 1 lyr Finishing Paint
Case 3	1.5 cm Plaster 20 cm ACC Block 1.5 cm Plaster	1.5 cm Indian Sandstone 5 cm Concrete Screed 15 cm RCC 1 cm Sand 1	4 cm Concrete Screed 11 cm Brick 1 lyr PE 1.5 cm Plaster 0.6 cm Gypsum Plaster 1 lyr Finishing Paint
Case 4	0.6 cm gypsum plaster 1 lyr Finishing Paint	15 cm Crushed Brick Earth Base	Concrete Screed RCC Slab 1.5 cm Plaster 0.6 cm Gypsum Plaster 1 lyr Finishing Paint
Case 5	1.5 cm Plaster 24 cm Solid Brick Wiener Berger/Porotherm	1.5 cm Indian Sandstone 5 cm Concrete Screed 15 cm RCC	1 cm Concrete Screed top layer 12 cm RCC Slab 1.5 cm Plaster 0.6 cm Gypsum Plaster lyr Finishing Paint
Case 6	1.5 cm Plaster 0.6 cm Gypsum plaster 1 lyr Finishing Paint	1 cm Sand 1 15 cm Crushed Brick Earth Base	4 cm Concrete Screed 11 cm Brick 1 lyr PE 1.5 cm Plaster 0.6 cm Gypsum Plaster 1 lyr Finishing Paint

Table 2: Layer orders of standard method-based building.

Layer Orders – Standard Method (Material from Outside to Inside)			
	Exterior wall	Floor	Roof Slab
Case 1-a	1.5 cm Plaster 16 cm PS Insulation 23 cm Brick 1.5 cm Plaster	1-1.5cm Tile/marble 1 Lyr mortar 5 cm cement Estrich 1 lyr PE foil	3 cm concrete tiles 4 cm crushed basalt aggregates 1 layer geotextile 1 lyr PVC waterproofing 15 cm thermal Insulation (XPS) 1 layer vapor barrier foil 12 cm RCC 1.5 cm Plaster 0.6 cm Gypsum Plaster 1 Lyr Finishing Paint
Case 2-a	0.6 Gypsum Plaster 1 lyr Finishing Paint	12 cm thermal Insulation 1 layer of WP 15 cm thick concrete slab 15 cm sand/gravel	1 lyr PVC Waterproofing 1 lyr Geotextile 15 cm insulation vapor barrier 1 lyr vapor barrier foil 4 cm structure Concrete 11 cm Brick Floor 1.5 cm Plaster 0.6 cm Gypsum Plaster 1 lyr Finishing Paint
Case 3-a	1.5 cm Plaster 16 cm PS Insulation 20 cm ACC Block 1.5 cm Plaster 0.6 cm gypsum plaster 1 lyr Finishing Paint	1-1.5cm Tile/marble 1 Lyr mortar 5 cm cement Estrich 1 lyr PE foil 10-15 cm thermal Insulation 1 layer of WP 15 cm thick concrete slab 15 cm sand/gravel	3 cm concrete tiles 4 cm crushed basalt aggregates 1 layer geotextile 1 lyr PVC waterproofing 1 lyr Geotextile 15 cm thermal Insulation (XPS) 1 layer vapor barrier foil 12 cm RCC 1.5 cm Plaster 0.6 cm Gypsum Plaster 1 Lyr Finishing Paint
Case 4-a			1 lyr PVC Waterproofing

			1 lyr Geotextile 15 cm insulation vapor barrier 1 lyr vapor barrier foil 4 cm structure Concrete 11 cm Brick Floor 1.5 cm Plaster 0.6 cm Gypsum Plaster 1 lyr Finishing Paint
Case 5-a	1.5 cm Plaster 16 cm Insulation 24 cm Solid Brick Wiener Berger/Porotherm 1.5 cm Plaster 0.6 cm Gypsum plaster 1 lyr Finishing Paint	1-1.5cm Tile/marble 1 Lyr mortar 5 cm cement Estrich 1 lyr PE foil 10-15 cm thermal Insulation 1 layer of WP 15 cm thick concrete slab 15 cm sand/gravel	3 cm concrete tiles 4 cm crushed basalt aggregates 1 layer geotextile 1 lyr PVC waterproofing 1 lyr Geotextile 15 cm thermal Insulation (XPS) 1 layer vapor barrier foil 12 cm RCC 1.5 cm Plaster 0.6 cm Gypsum Plaster 1 Lyr Finishing Paint
Case 6-a			1 lyr PVC Waterproofing 1 lyr Geotextile 15 cm insulation vapor barrier 1 lyr vapor barrier foil 4 cm structure Concrete 11 cm Brick Floor 1.5 cm Plaster 0.6 cm Gypsum Plaster 1 lyr Finishing Paint

2.3 Exterior and Interior Wall

The exterior wall is the main building component for safety, stability, and durability. In a load-bearing structure, the load of the slab and beams is bear by an exterior wall while in the case of a skeleton building these walls work as an infill wall. These days walls are constructed by using various types of bricks and blocks. In India, most of the exterior walls are constructed by using fired clay brick with a frog on one side of the brick surface, and in some places, we started to use ACC bocks for wall construction. The size of the bricks

is generally used for modular or standard brick (190x90x90 mm) and non-modular brick (230x110x70 mm). Exterior and interior walls are generally constructed with layers in the following ways Cement plaster, Brick, Cement Plaster, and a finishing surface with gypsum and paints. In this research, we created two main cases with and without insulation and analyzed energy consumption concerning thermal conductivity limit. Three materials used for exterior walls are fired clay bricks, ACC Block, and Porothersm or Wiener Berger solid brick.

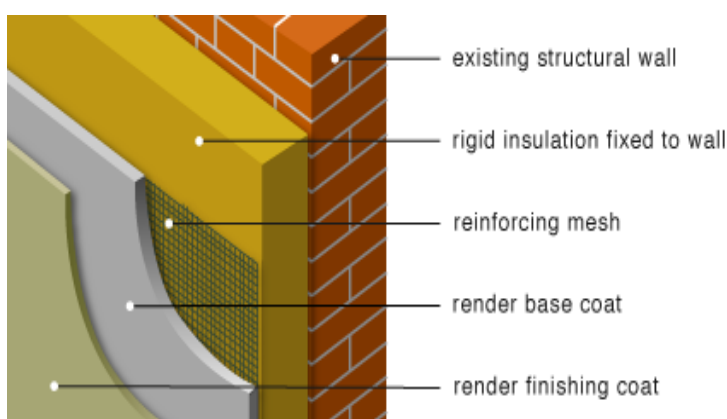


Figure 9:Exterior wall cross-section (Source: Google)

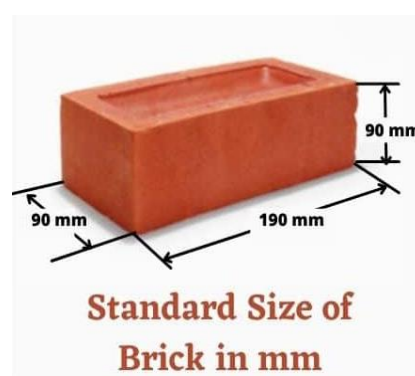


Figure 10:Standard Brick with frog

2.4 Floor

The construction of the ground floor begins when the foundation has been laid, all trenches have been backfilled, and load-bearing walls constructed up to the damp-proof Course (DPC). The load-bearing part of the floor is constructed in various ways such as reinforced concrete slab, and brick floor. In most areas, the traditional ways of construction are adopted due to cheap estimates. They are not providing correct layers therefore they face moisture and mold problems in the building. Two different types of floors are used in this study, one based on old techniques and the second based on current standards.

2.5 Slab

Flat roof construction is a prevalent trend in India, with a variety of slabs employed in the process, including brick slab, RCC slab, and Porothersm slab. Table 1 and 2 outline the layers and assembly construction involved in this study. The traditional approach entails constructing the slab without incorporating any insulation, while the second standard method introduces insulation for enhanced thermal properties.



Figure 11: Brick Slab with reinforcement[17]

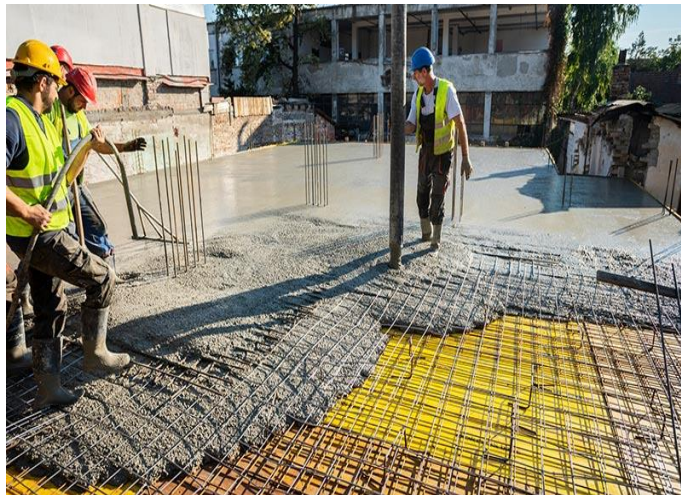


Figure 12: Reinforced Cement Concrete[18]

2.6 Windows and Doors

Windows and doors are essential to the operation and aesthetic of a building. They let in natural light while also offering ventilation. Several types of windows include casement, double-hung, sliding, and fixed windows. These days come in different styles in the market such as swinging, sliding, folding, and pocket doors. Energy-efficient windows help with temperature adjustment and reduce heating and cooling costs. Double glazing, low-E coatings, and gas filling all contribute to increased energy efficiency. The materials chosen, such as wood, aluminum, or UPVC, influence durability and appeal. Design concerns are significant because varied designs and shapes affect the overall appearance of a structure. Maintenance requirements differ depending on the material, and accessibility issues are critical for doors that fulfill many

functions. Finally, windows and doors improve the functioning, energy efficiency, security, and overall design of a structure, as well as the comfort and aesthetics of a room.

2.7 Material Properties

Table 3: Materials Properties

Materials Properties	Concrete, w/c 0.5	Concrete Screed, top layer	Cement Plaster	Interior Gypsum Plaster	Mortar (historical): Lime + Cocciopesto (crushed bricks)	Sand
Bulk density [kg/m ³]	2300	1890	2000	850	1576	1579
Porosity	0.18	0.2	0.3	0.65	0.44	0.404
Specific heat capacity [J/kgK]	850	850	850	850	850	850
Thermal conductivity, dry, 10 C/50 F [W/mK]	1.6	1.6	1.2	0.2	0.58	0.505
Water vapor diffusion resistance factor	180	58	25	8.3	7.02	50
Typical built-in moisture [kg/m ³]	150	168	280	400	328.96	0
Reference water content [kg/m ³]			35		4.21	
Free water saturation [kg/m ³]			280		328.96	
Thermal conductivity supplement [%/M.-%]	8		10	8	0.27	

Table 4: Materials Properties

Materials Properties	Solid Brick Masonry	Wienerberger Solid Brick	Indian Sandstone New	XPS	Mineral Wool	Expanded Polystyrene Insulation
Bulk density [kg/m ³]	1900	1744	2263	28.6	60	14.8
Porosity	0.24	0.33	0.15	0.99	0.95	0.99
Specific heat capacity [J/kgK]	850	889	875	1470	850	1470
Thermal conductivity, dry, 10 C/50 F [W/mK]	0.6	0.5438	2.791	0.025	0.04	0.036
Water vapor diffusion resistance factor	10	15	64	170.56	1.3	73.01
Typical built-in moisture [kg/m ³]	100	100	0	0.13	0	0.06
Reference water content [kg/m ³]	18	2.5	11			
Free water saturation [kg/m ³]	190	287	69			
Thermal conductivity supplement [%/M.-%]	15	8	8			

2.7.1 Concrete, w/c 0.5

Since reinforced cement concrete detail is not available in the Wufi Plus database, we substituted concrete with a water-cement ratio of 0.5 in its place. The density of Reinforced cement concrete is 2500 kg/m^3 , while the density of plain cement concrete is 2300 kg/m^3 . The difference is due to the usage of steel bars in RCC, whereas no steel is used in PCC. This is used to build load-bearing constructions such as floors, beams, columns, and slabs. Figures 13 depict the relative humidity and thermal conductivity of concrete, with temperature and water content respectively.

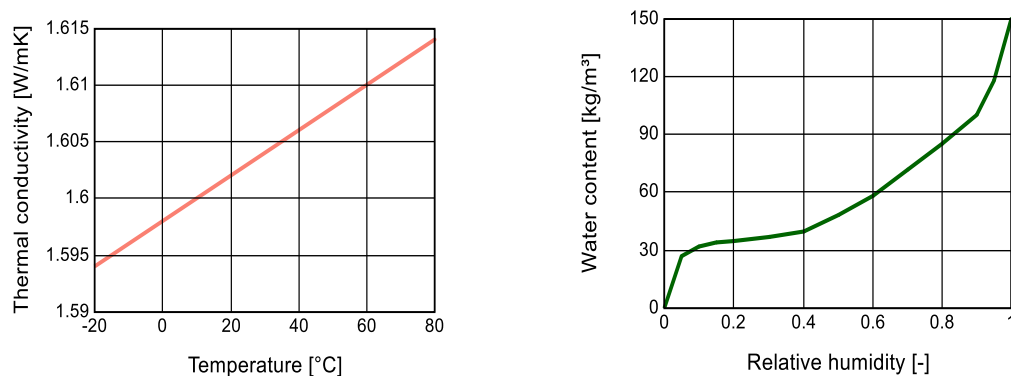


Figure 13: Concrete – Left: Thermal Conductivity and Temperature Right: RH and Water Content

2.7.2 Concrete Screed Top Layer

Concrete screed is an enthralling part of construction! A concrete layer is applied to a surface to provide a smooth, flat, and level finish. It is composed of cement, sand, and water, or just cement and water. It differs from both regular and reinforced cement concrete. Furthermore, if we plan to install additional layers such as tiles, marble, wood, and so on, we can use this layer as well, but mortar will be more efficient. After the concrete has been placed, the surface is frequently levelled using a trowel. Screeds are available in a range of designs, including traditional hand screeds and more advanced robotic screeds. The option is chosen by the unique requirements of the project. The thermal conductivity and RH of concrete screed can be found in Fig. 14.

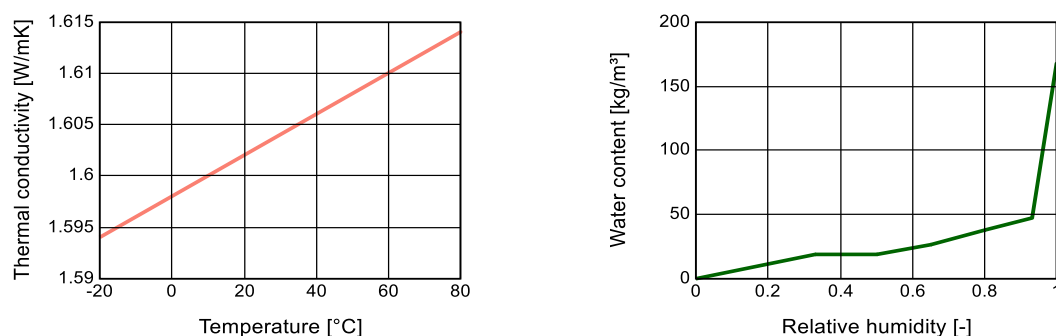


Figure 14: Concrete Screed - (Left) Temperature and Thermal conductivity (Right) RH and water content.

2.7.3 Cement Plaster

Cement plaster, often known as stucco, is a long-lasting building material used to coat walls and ceilings. It is made of cement, sand, and water and is put in layers—scratch coat, brown coat, and finish coat—to create a smooth, textured, or patterned surface. Cement plaster is well-known for its durability, fire resistance, and adaptability in giving both a protective and ornamental finish. Proper surface preparation and upkeep are required, and it can be utilized for both indoor and exterior applications. Figure 16, represent two main properties required for hygrothermal analysis and TC reaches 1.214 W/mK at 80-degree temperature.

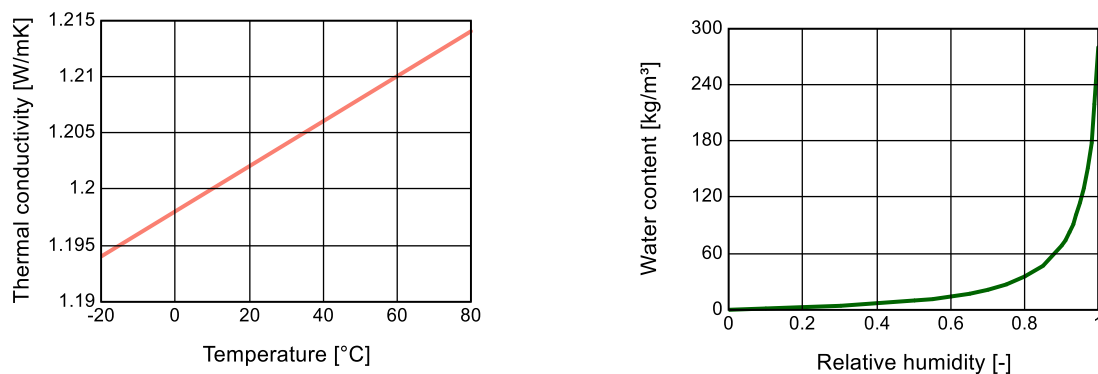


Figure 16: Cement Plaster - (Left) Temperature and Thermal conductivity (Right) RH and water content.

2.7.4 Interior Plaster (Gypsum Plaster)

Gypsum plaster, often known as plaster of Paris, is a common building and finishing material. It is applied on the finishing surface and utilized to create interior designs in accordance with interior design specifications. Gypsum plaster is created from the mineral gypsum, which is a soft sulphate. It creates a paste when mixed with water and can be applied to walls and ceilings. As it dries, gypsum plaster goes through a chemical setting process. It hardens and develops a solid surface during this process. Setting time varies depending on the type of gypsum plaster used. TC increases due to increase in temperature (Figure 17).

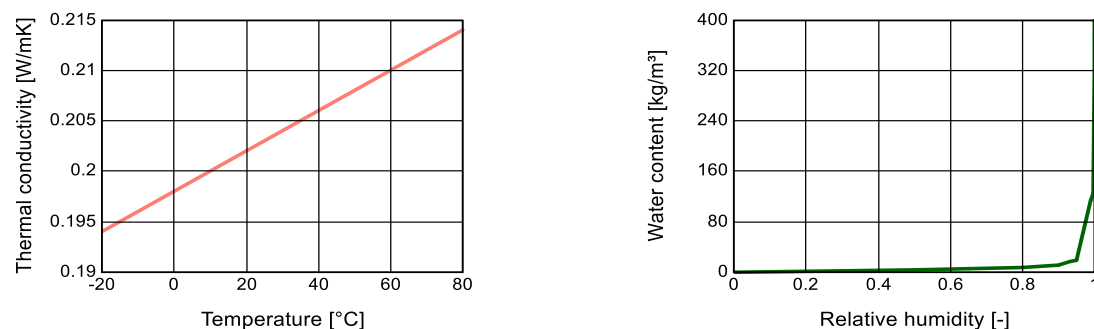


Figure 17: Interior Gypsum Plaster- (Left) Temperature and Thermal (Right) RH and water content.

2.7.5 Mortar (historical): Lime + Cocciopesto (crushed bricks)

This material is utilized to build the foundation and floor's base. Before beginning the major foundation and floor construction, we usually employed crushed brick, gravel with sand, and cement to make the bed horizontal and robust. It varies by location; in certain areas, crushed brick, overburnt brick, gravel, old building materials, and so on are used. The water content is zero until the relative humidity approaches 90%, as seen in Fig. 18. In my opinion, the supplied name mortar lime is inappropriate for this, but I relied on it because it is in the Wufi Plus database. This refers to the foundation material used to make the earth bed level horizontal.

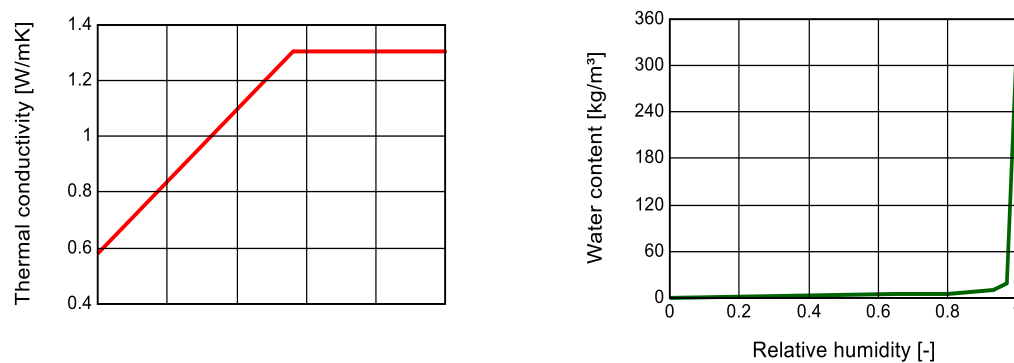


Figure 18: Crushed Brick- (left) Thermal Conductivity and Temperature (Right) RH and Water Content

2.7.6 Solid Brick

Solid bricks are a traditional building material made of clay that has been baked in a kiln. These bricks can be manufactured by hand or by machine. Bricks are generally impermeable and have a high porosity with limited water absorption. The strength and durability of solid bricks are well known. They're frequently seen in load-bearing structural parts. The lack of voids in solid bricks helps to their resistance to compressive forces. The solid bricks have a 10cm x 40 cm x 1 cm deep frog on one side to strengthen the link between two layers in wall construction or the slab. First-class brick has an average strength of 7.5 N/mm² to 10.5 N/mm²[19]. These bricks are divided into three classes based on their strength. Fig 19 depicts TC 0.614 W/mK at 80-degree temperature.

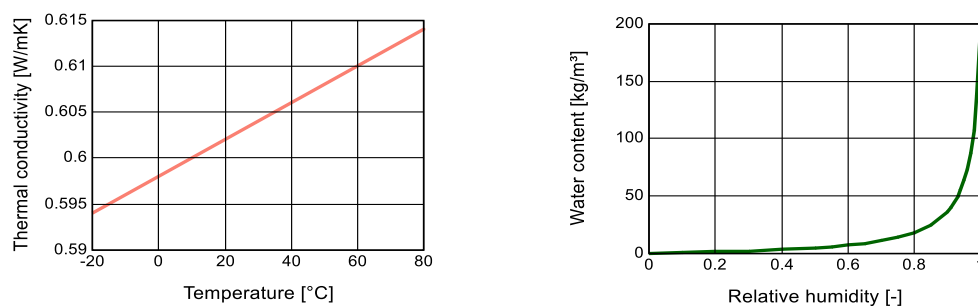


Figure 19: Solid Brick- (left) Thermal Conductivity and Temperature (Right) RH and Water Content

2.7.7 Extruded Polystyrene Insulation (XPS)

Extruded Polystyrene (XPS) is a stiff, closed-cell insulation material known for its great compressive strength and moisture resistance. It is widely utilized in construction and provides good thermal insulation for walls, roofs, and foundations. Extrusion produces a dense and durable foam with improved resistance to water absorption. Its versatility extends to infrastructure applications, providing a dependable option for insulating roads and trains. XPS is valued for its longevity, resistance to decay, and stability across a wide temperature range, making it a popular choice for projects requiring strong and dependable insulation.

Fig 20 shows the TC and RH at different temperature.

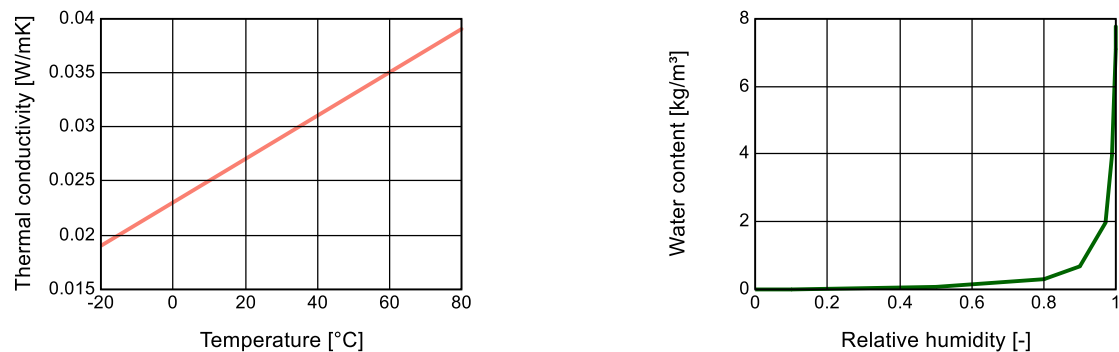


Figure 20: XPS- (left) Thermal Conductivity and Temperature (Right) RH and Water Content

2.7.8 Expanded Polystyrene Insulation (EPS)

Expanded Polystyrene (EPS) is a lightweight, versatile insulating material that is often used in construction due to its high level of thermal insulation. Its low thermal conductivity promotes energy efficiency, with applications ranging from walls to roofs and floors. EPS is a popular choice among builders because of its ease of handling and installation, as well as its low cost. Recyclability solves environmental issues, and some kinds incorporate flame retardants for improved fire resistance. Adhering to local building codes and inspecting product specifications assures the responsible and effective use of EPS in construction, balancing efficiency, and environmental considerations. TC of EPS is 0.03 W/mK at -20-degree centigrade temperature.

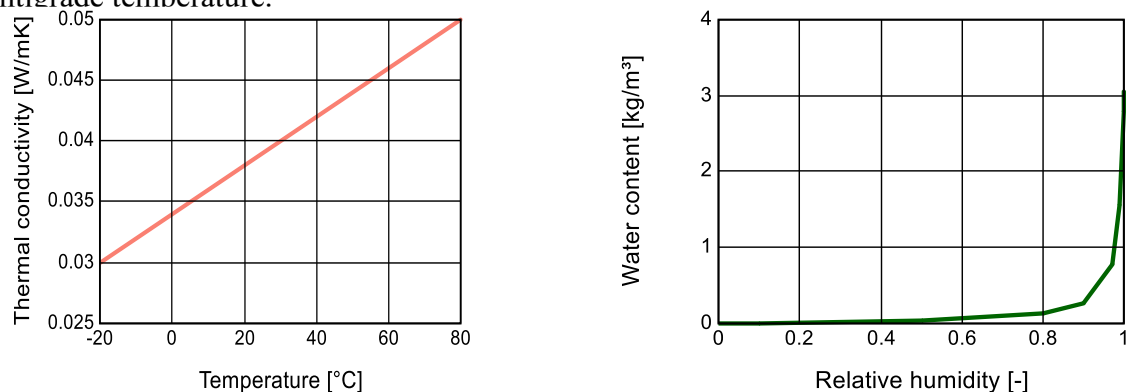


Figure 22: EPS- (left) Thermal Conductivity and Temperature (Right) RH and Water Content

2.7.9 Mineral Wool

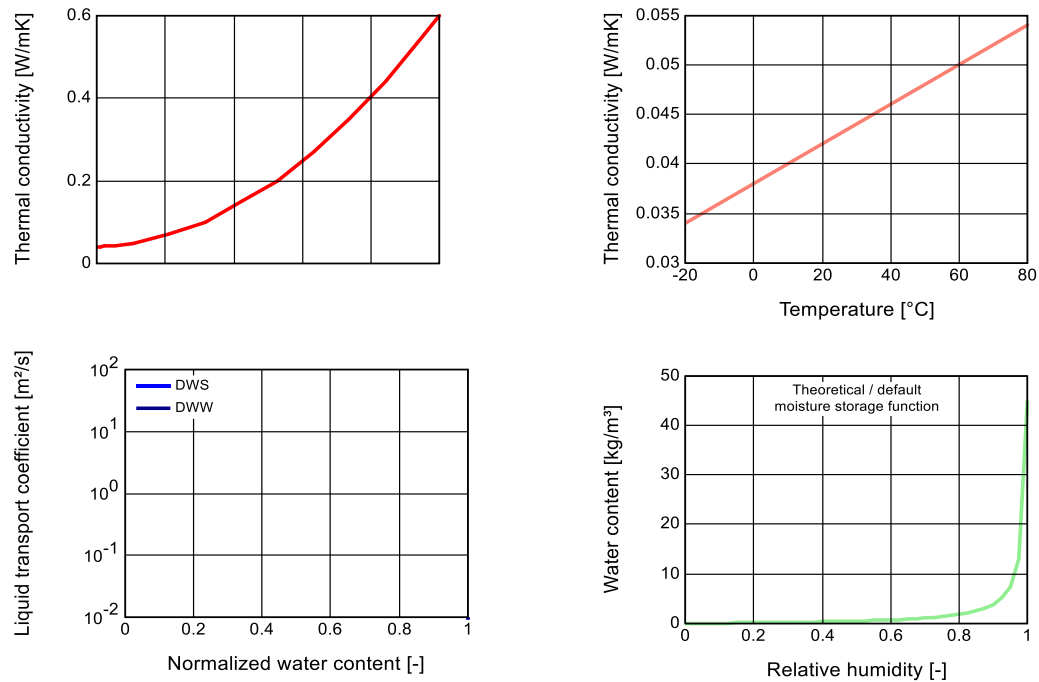


Figure 23: Mineral Wool- Top Left: Thermal conductivity Top Right: Temperature and Thermal Conductivity Bottom Left: Normalised water content and liquid transport coefficient Bottom Right: RH and water content.

2.7.10 Wienerberger Solid Brick

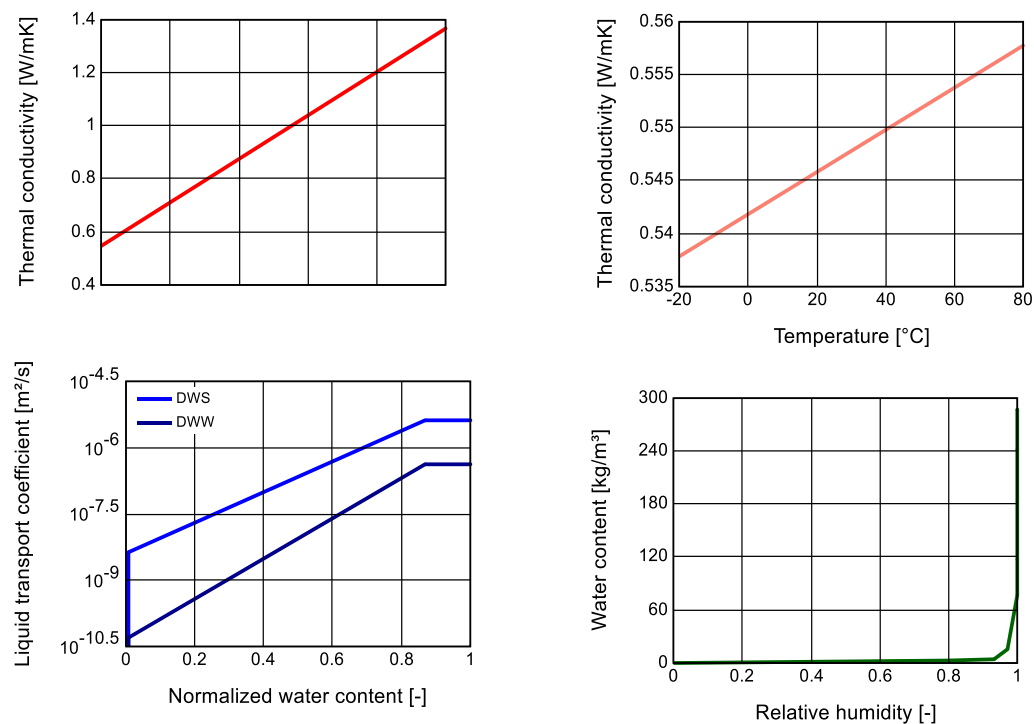


Figure 24: Wienerberger Solid brick Top Left: Thermal conductivity Top Right: Temperature and Thermal Conductivity Bottom Left: Normalised water content and liquid transport coefficient Bottom Right: RH and water content.

3. Dynamic hygrothermal simulation

3.1 Weather Description

This study focused on energy conservation in two cities: Bareilly and Budapest. For simulation, the Wufi family program requires hourly weather data. It contains information on temperature, humidity, rain, and sun radiation. The Figure 25 and 27 depicts the hourly temperature and relative humidity readings, while the center line connecting both graphs depicts the dynamic values.

Table 5: Weather Data	Bareilly	Budapest
Latitude [°]	28.3	47.4
Longitude [°]	79.4	19.2
Height MSL [m]	183	140
Time zone [Hours from UTC]	5.5	1
Additional data		
Albedo	User Defined	
Ground reflectance short	0.2	0.2
Ground reflectance long	0.1	0.1
Ground emission	0.9	0.9
Cloud Index (only WET file)	0.7	0.7
CO2-concentration [mg/m ³]	350	350

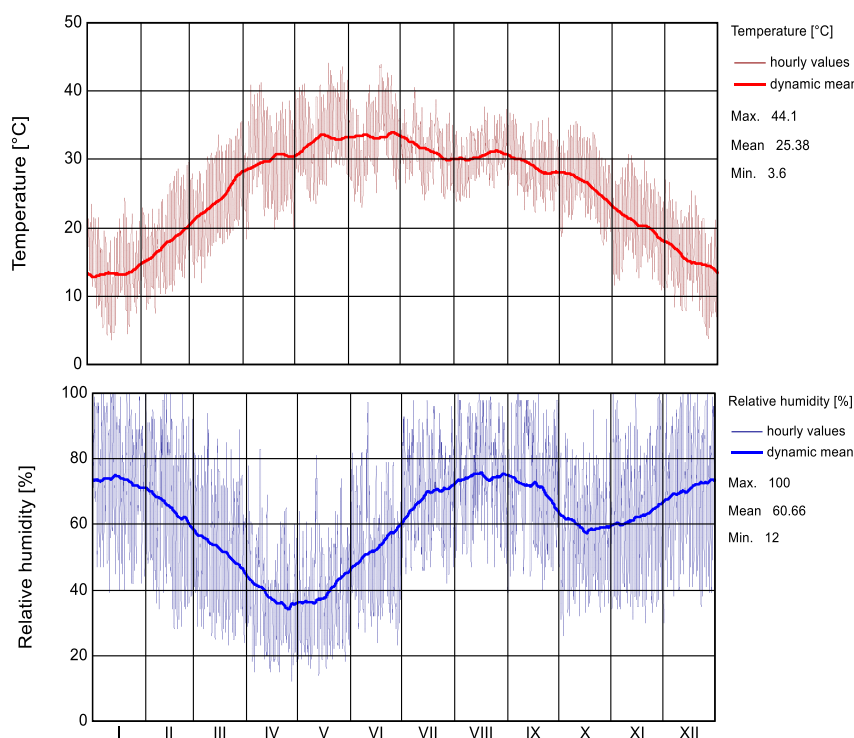


Figure 25: Temperature and Relative Humidity Bareilly

Bareilly is located 183 meters above mean sea level (MSL) in a subtropical region with latitude 28.30 N and longitude 79.40 E. The maximum temperature reached in July i.e., 41 degrees, and the coldest temperature reached in January i.e., 3.6 degrees. The temperature graph depicts the constant variation in temperature, and the average temperature of the air is 25.38. On the other hand, RH can reach a maximum of 100%, a minimum of 12%, and an average of 66%, and it is inversely proportional to temperature. The southern section receives the most solar energy, while the northern side receives the least[20], [21].

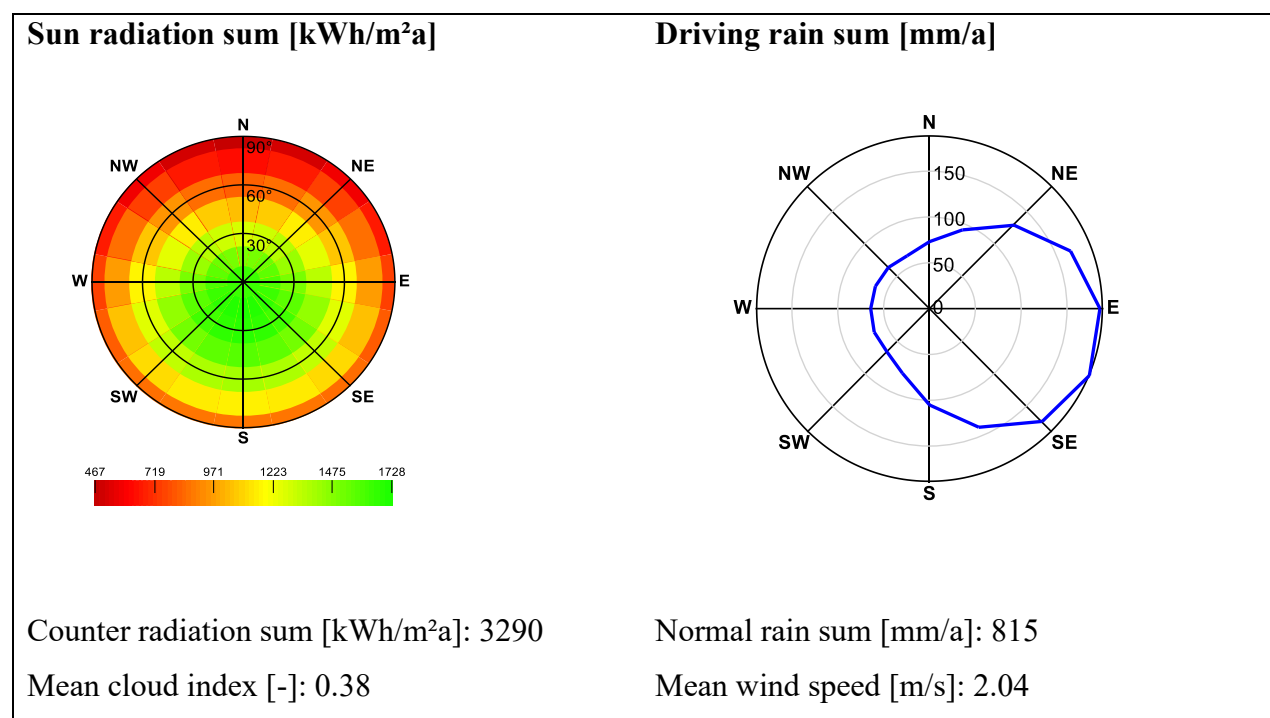


Figure 26: Bareilly solar radiation and wind-driven rain directional distributions (Taken from Wufi Plus Climate analysis)

Budapest has a humid continental climate with very hot summers and chilly, dry winters. It is located 140 meters above mean sea level (MSL) and has the coordinates latitude 47.430N and longitude 19.180 E. The maximum temperature in July is 36⁰ C, with a minimum of -10⁰ C in January and an average of 11 ⁰C. RH can be as high as 100%, as low as 24%, and as high as 67.8%. The rainy season lasts approximately a whole year from January to December, although there is also 0 (l/m2) rainfall in the months of March, July, and September, and the total annual vertical rainfall is 545.2 mm/year[22].

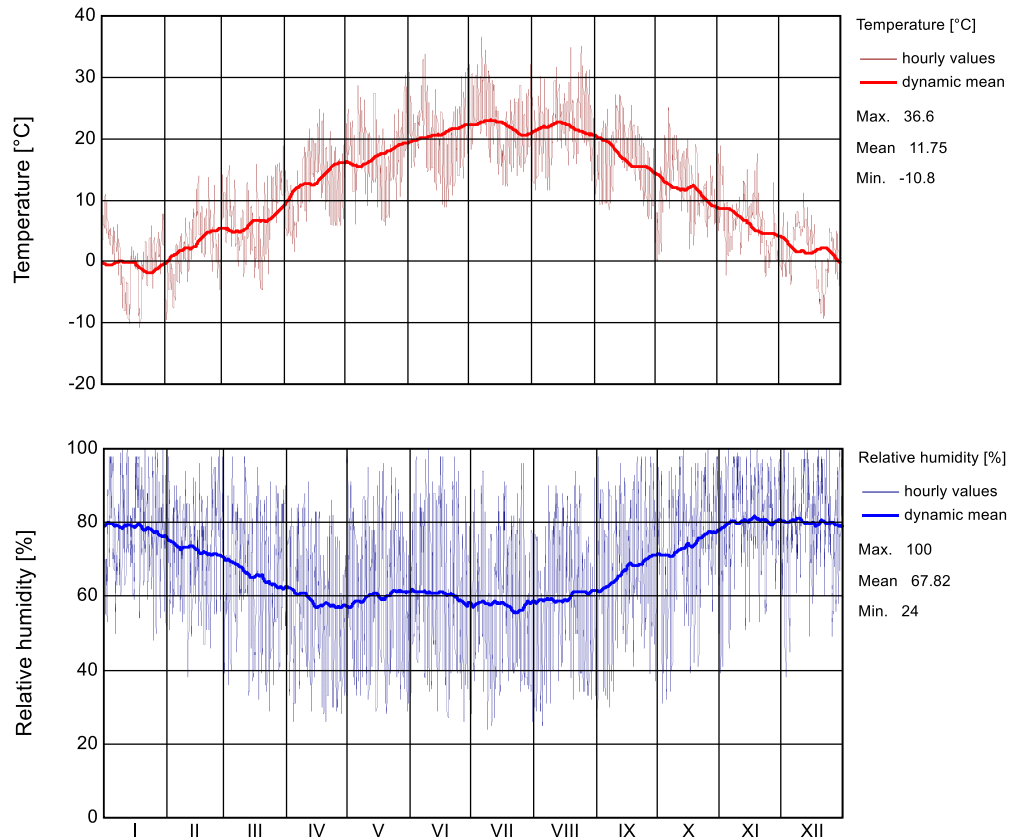


Figure: Climate Temperature and Relative Humidity Budapest

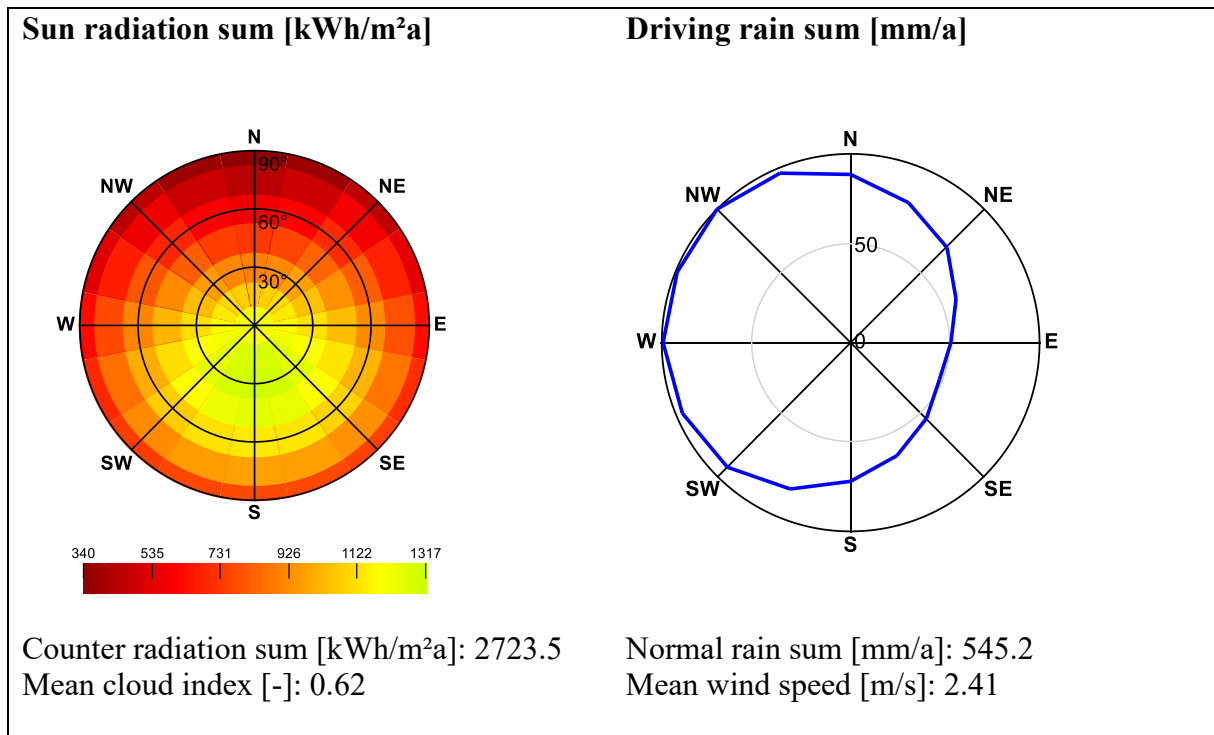


Figure 27: Budapest Solar radiation and wind driven rain directional distributions (Taken from Wufi Climate Analysis)

3.2 Boundary Conditions

In the context of steady-state simulations, the conventional practice typically involves setting boundary conditions without time-dependent functions, often relying on design values aligned with established standards or utilizing yearly and seasonal averages. In contrast, my methodology represents a departure from this norm by opting to incorporate monthly averaged values extracted from weather files for steady-state simulations. The central focus of these simulations revolves around temperature and relative humidity, serving as fundamental elements for defining boundary conditions. The deliberate exclusion of solar radiation and precipitation, given their dynamic nature, underscores the inadequacy of monthly averages in capturing their variability and consequential impact. The hourly weather data for Budapest and Bareilly was given by the supervisor, helped using Meteonorm. It is essential to note that this methodology intentionally omits a detailed exploration of microclimatic factors, such as wind patterns around buildings or local environmental influences. The resulting monthly averages, derived from the hourly weather files, constitute the foundational components for external boundary conditions. Importantly, the absence of instances where external relative humidity surpasses 80% in these monthly averages renders liquid transport inconsequential within the context of steady-state simulations. Internal conditions of air and equivalent vapor diffusion thickness of boundary layers were set according to EN 15026[23].

3.3 Wufi Plus software

The main purpose of the complete building simulation is to plan energy use and optimization to consider the resident's comfort inside the building. In this study, we used Wufi Plus hygrothermal simulation Software developed by the Fraunhofer Institute for Building Physics, Germany. It is a very powerful software tool designed for dynamic hygrothermal simulations based on the calculation model developed by Kunzel (1994)[24], which corresponds to the specifications of DIN EN 15026[23], providing a comprehensive stage for evaluating the dynamic performance of building envelopes. Its advanced numerical method enables the heat and moisture simulation of the entire building and provides insights into the interplay between environmental conditions and building components over time. Simulations are based on user-specified hourly climate and user-defined ventilation, HVAC, and internal loads. The first calibration approach and development of the Wufi plus model is by comparing its simulation results to the measured data of field experiments that is documented by Lengsfeld and Holm 2007[25]. Architects,

engineers, and researchers control its capabilities for practical applications, making informed decisions about insulation strategies, material choices, and HVAC system design. In the broader context of sustainable building practices and global initiatives for energy conservation, Wufi Plus stands as an indispensable tool, contributing to the creation of resilient, energy-efficient, and comfortable built environments. Simulation of the interaction between building usage and system technology allows for integral assessment of indoor climate, hygienic conditions, thermal comfort, indoor air quality, and damage to components as a function of heating and cooling loads and the necessary effort to humidify/dehumidify. The climate data mainly used in this software contains outdoor air temperature, relative humidity, wind speed, and direction, normal rain, and solar radiation data, which influence the exterior building envelope. The Wufi Plus was developed with the ambition to be a reliable and easy-to-operate calculation tool for architects, researchers, and engineers. Wufi Plus is widely used these days for hygrothermal 1D, 2D, and 3D simulations of buildings[26], [27].

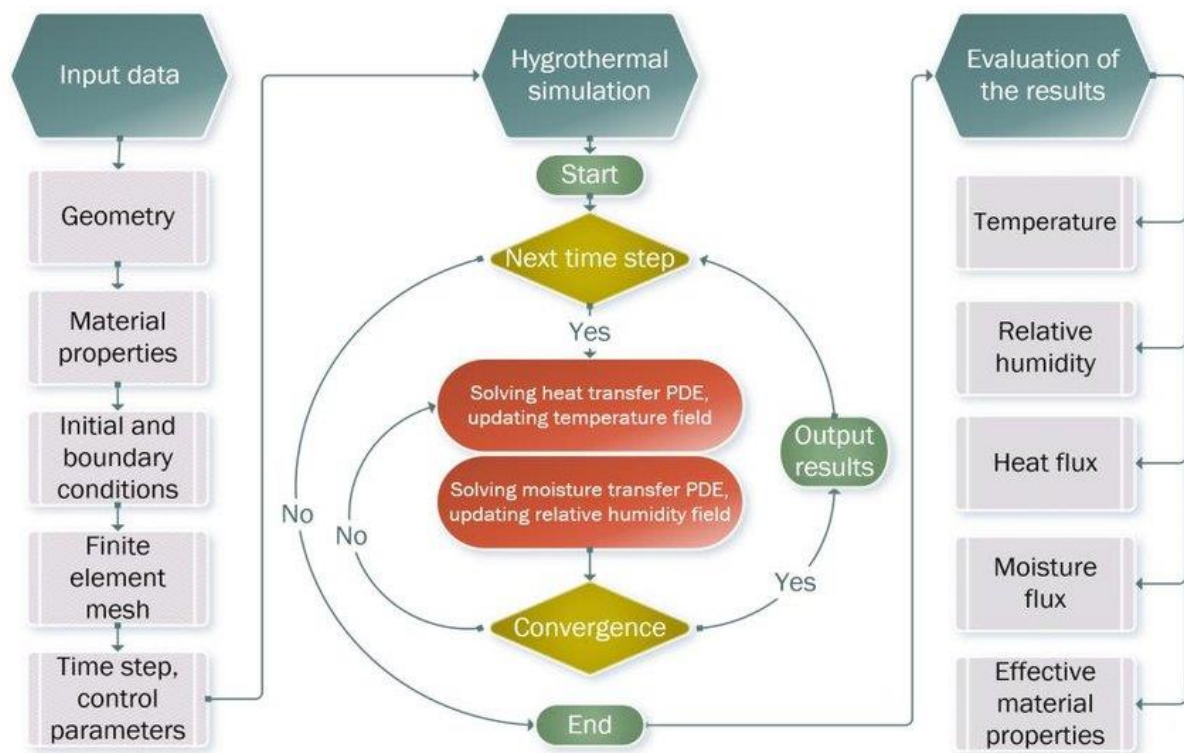


Figure: Schematic flow chart of the hygrothermal modeling process[28]

4. Result and Discussion

In terms of results, we are discussing two different cases separately below with some graphical representation.

4.1 Un-insulated Building

In this study, we conducted an analysis of six uninsulated buildings constructed with various materials. Figure 28 presents the overall energy gain or loss observed in these uninsulated buildings, while Table 6 breaks down the energy gain/loss by building components. Our investigation focused on a traditional building modelled in Wufi Plus software, examining its performance in two distinct locations with contrasting climates. In the Bareilly zone, the traditional building exhibited a total energy gain of 73%, with approximately 27% energy loss. However, when situated in Budapest, the same building proved unsuitable for the climate, showing only a 15% total energy gain and an 85% energy loss. The detailed breakdown of energy gain and loss is summarized in Table 7.

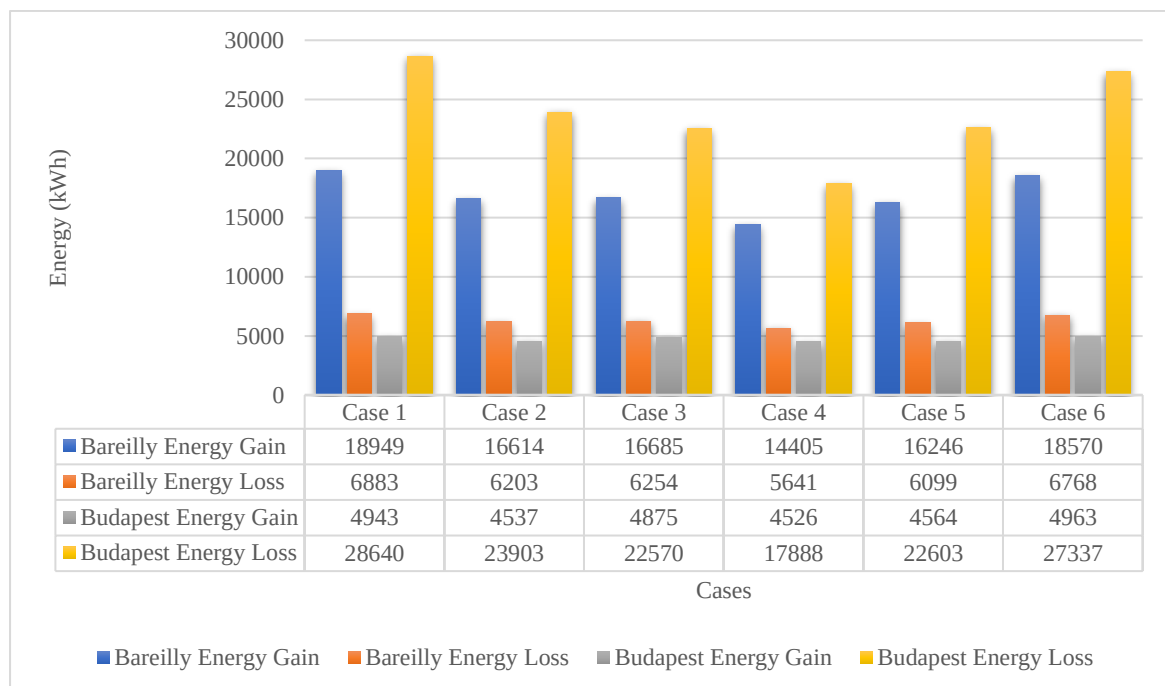


Figure 28: Comprehensive Energy Fluctuations in Non-Insulated Structures

Figure 28 illustrates the overall energy fluctuations within an uninsulated building in both Budapest and Bareilly. It indicates a predominant trend where energy loss outweighs energy gain in Budapest, whereas in Bareilly, the building experiences a surplus of energy gain over loss.

Table 6: Energy gain/loss by a component of uninsulated building

Case	Component group	Bareilly		Budapest	
		Gain	Loss	Gain	Loss
Case 1	Outer walls	5437	1031	667	9252
	Flat roof	7992	1547	721	14433
	Floor to unconditioned space	47	3530	518	1043
	Windows	5473	775	3037	3912
Case 2	Outer walls	5315	936	512	9171
	Flat roof	5783	943	512	9754
	Floor to unconditioned space	33	3530	470	1034
	Windows	5483	794	3043	3944
Case 3	Outer walls	3269	350	790	2938
	Flat roof	7896	1545	554	14540
	Floor to unconditioned space	58	3574	513	1135
	Windows	5462	785	3018	3957
Case 4	Outer walls	3177	277	676	2871
	Flat roof	5721	972	388	9881
	Floor to unconditioned space	38	3582	442	1134
	Windows	5469	810	3020	4002
Case 5	Outer walls	4951	796	564	7809
	Flat roof	5786	964	506	9795
	Floor to unconditioned space	30	3543	455	1043
	Windows	5479	796	3039	3956
Case 6	Outer walls	5067	886	717	7891
	Flat roof	7990	1565	707	14475
	Floor to unconditioned space	43	3541	506	1050
	Windows	5470	776	3033	3921

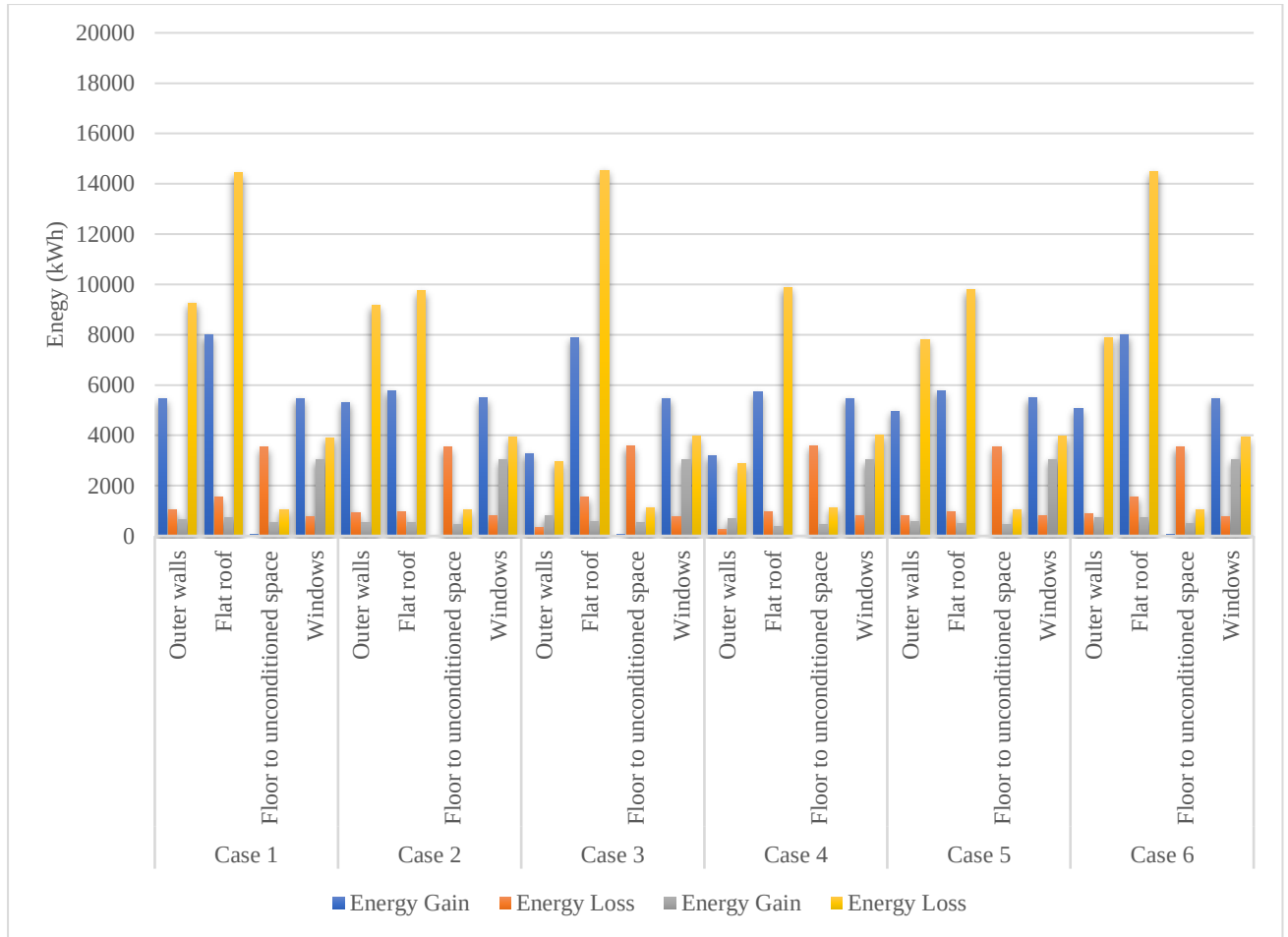


Figure 29: Energy Fluctuations by Component in Non-Insulated Structures

Figure 29, depicts the energy fluctuations of individual building components, comprising six scenarios of non-insulated buildings. Each case highlights the primary component responsible for significant energy consumption. Case 1,3 and 6 have high amounts of heat loss through flat slab with brick in Budapest while case 2,4 and 5 have energy loss approximately 9000 kWh in flat slab with RCC.

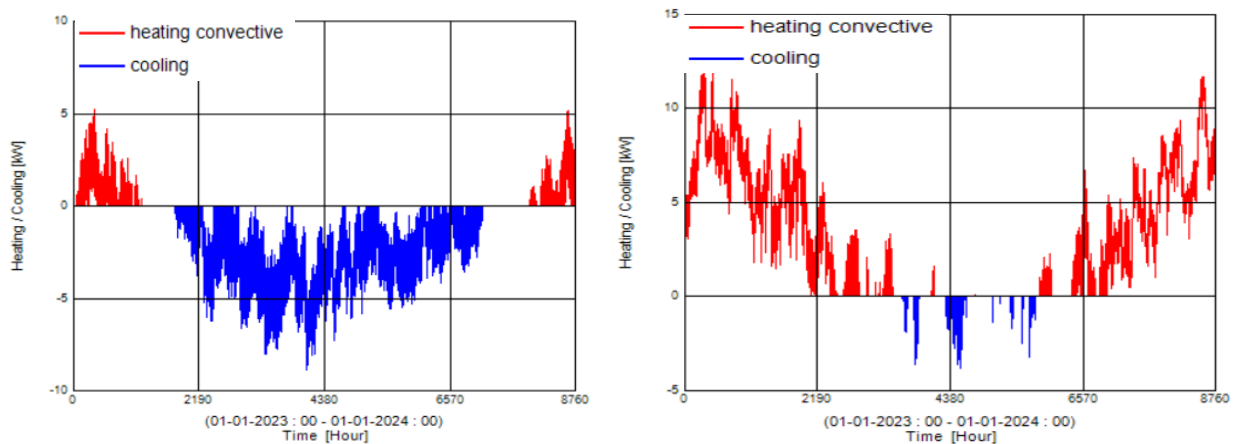


Figure 30: Hourly representation of heating and cooling in uninsulated building (left: Bareilly Right: Budapest)

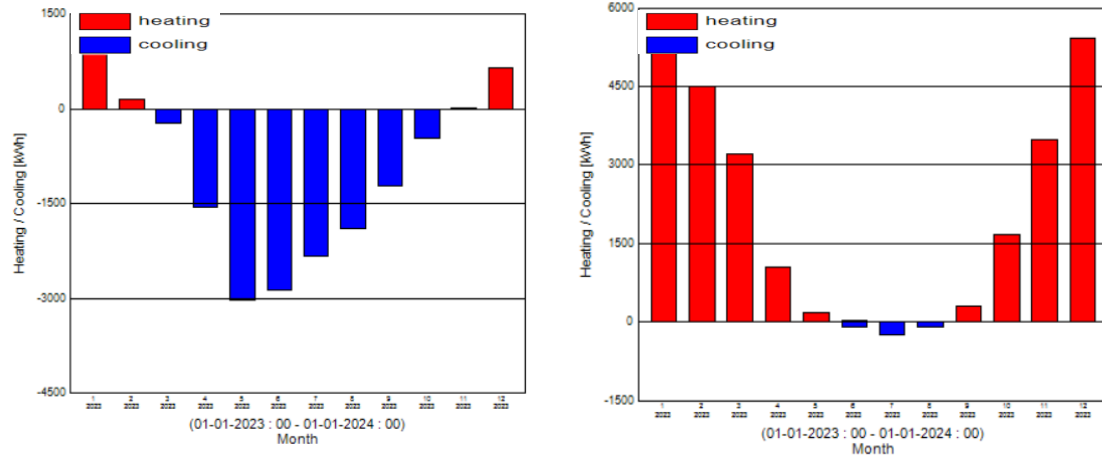


Figure 31: Monthly energy consumption due to heating and cooling in an Uninsulated family house (left: Bareilly, right: Budapest)

Figures 30 and 31 illustrate the annual heating and cooling consumption needs of Bareilly and Budapest. The graphical representation reveals a demand for heating extending from December to mid-February, totalling 5 kW/hr in Bareilly and 12 kW/hr in Budapest for approximately 9 months. Notably, this data spans from 0 hr to 1800 hr and from 7000 hr to approximately 8760 hr for the heating period in Bareilly. On the other hand, span from 0hr to 3950 hr and 6300 hr to 8760 hr in Budapest. Conversely, the cooling period spans from mid-February to the end of November (1800 hr to 7000 hr), with a consumption range of approximately 7 to 8.5 kWh during this timeframe in Bareilly and only for 3 months in Budapest on an average 5 kWh. In figure 31 illustrate the monthly energy consumption of an uninsulated building.

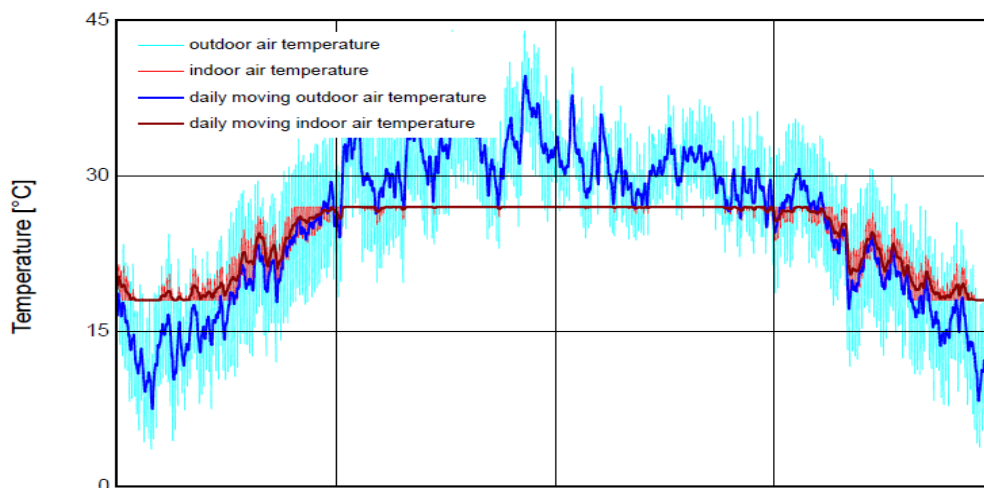


Figure 32: Overheating climate of uninsulated buildings, Bareilly

In Fig. 32, the fluctuations in indoor and outdoor air temperatures throughout the year are depicted. The ideal range for indoor air temperature is around 18 to 25 degrees Celsius.

However, from April to September, outdoor temperatures exhibit abrupt variations. To ensure comfortable living conditions, a horizontal line is maintained during this period, signifying a consistent indoor air temperature. Achieving this stability relies on the utilization of external mechanical and electrical devices.

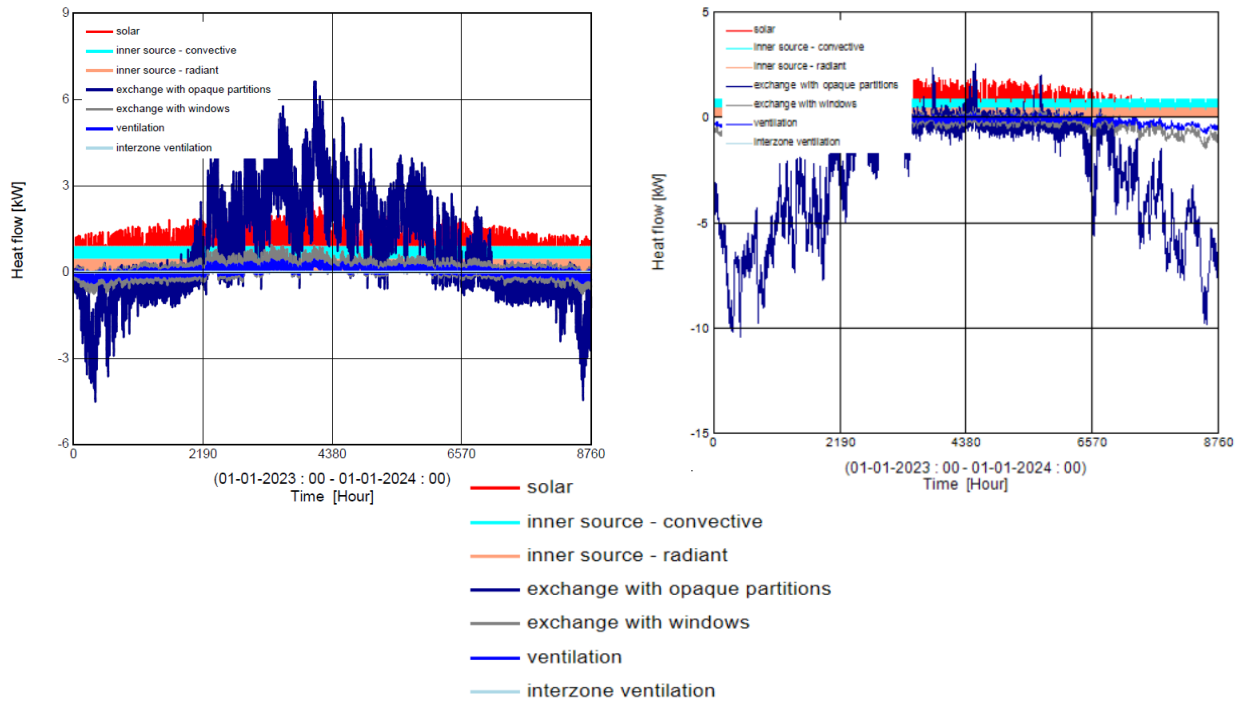


Figure 34: Hourly heat flows in an uninsulated family house (left: Bareilly and right: Budapest)

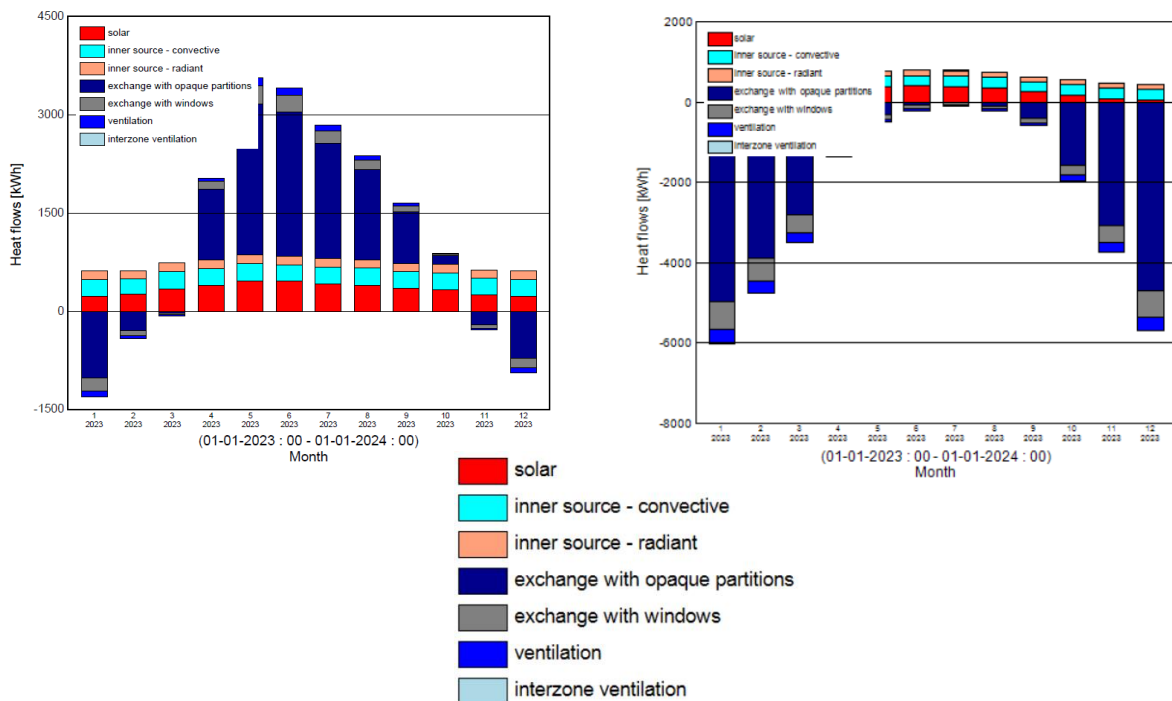


Figure 33: Monthly heat flows in an uninsulated family house (left: Bareilly right: Budapest)

4.2 Insulated Buildings

When considering insulated buildings, we observed that the windows selected for the Bareilly zone proved unsuitable for Budapest, leading to significant energy loss. These windows require replacement with modern, energy-efficient alternatives to mitigate their substantial energy consumption and loss compared to other components. In insulated buildings, the total energy gain is 85%, with only a 15% loss in the Bareilly zone. Conversely, in Budapest, the total gained energy is 44%, with a corresponding 56% loss. This indicates that the building, constructed using standard methods, is not well-suited for Budapest due to the substantial energy loss and differing climate. To address this, adjustments to the layer order and the incorporation of additional necessary layers are essential for Budapest. Figure 35 provide a comprehensive overview of the total energy gain or loss and energy dynamics within the main components of the buildings.

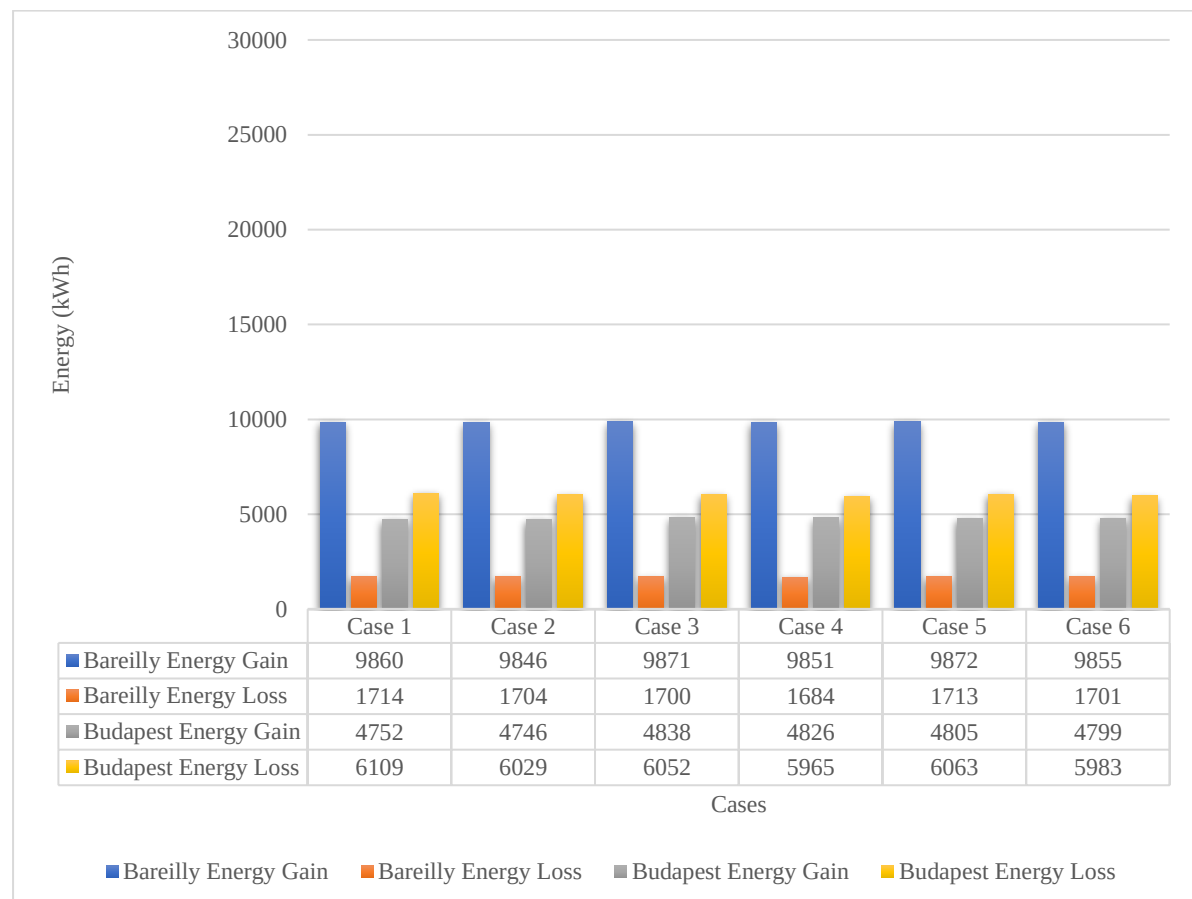


Figure 35: Total energy gain/loss in an insulated family house

Table 7: Energy gain/loss by a component of insulated building

Case	Component group	Bareilly		Budapest	
		Gain	Loss	Gain	Loss
Case 1_a	Outer walls	2232	124	622	774
	Flat roof	1706	133	516	603
	Floor to unconditioned space	565	167	643	57
	Windows	5357	1290	2971	4675
Case 2_a	Outer walls	2242	137	631	784
	Flat roof	1676	104	498	512
	Floor to unconditioned space	571	174	647	61
	Windows	5357	1289	2970	4672
Case 3_a	Outer walls	2186	56	644	634
	Flat roof	1743	170	557	650
	Floor to unconditioned space	587	189	668	87
	Windows	5355	1285	2969	4681
Case 4_a	Outer walls	2192	63	649	639
	Flat roof	1710	140	533	554
	Floor to unconditioned space	595	198	675	94
	Windows	5354	1283	2969	4678
Case 5_a	Outer walls	2236	104	681	701
	Flat roof	1711	140	515	610
	Floor to unconditioned space	568	172	639	59
	Windows	5357	1297	2970	4693
Case 6_a	Outer walls	2246	115	689	710
	Flat roof	1680	111	497	519
	Floor to unconditioned space	573	179	643	64
	Windows	5356	1296	2970	4690

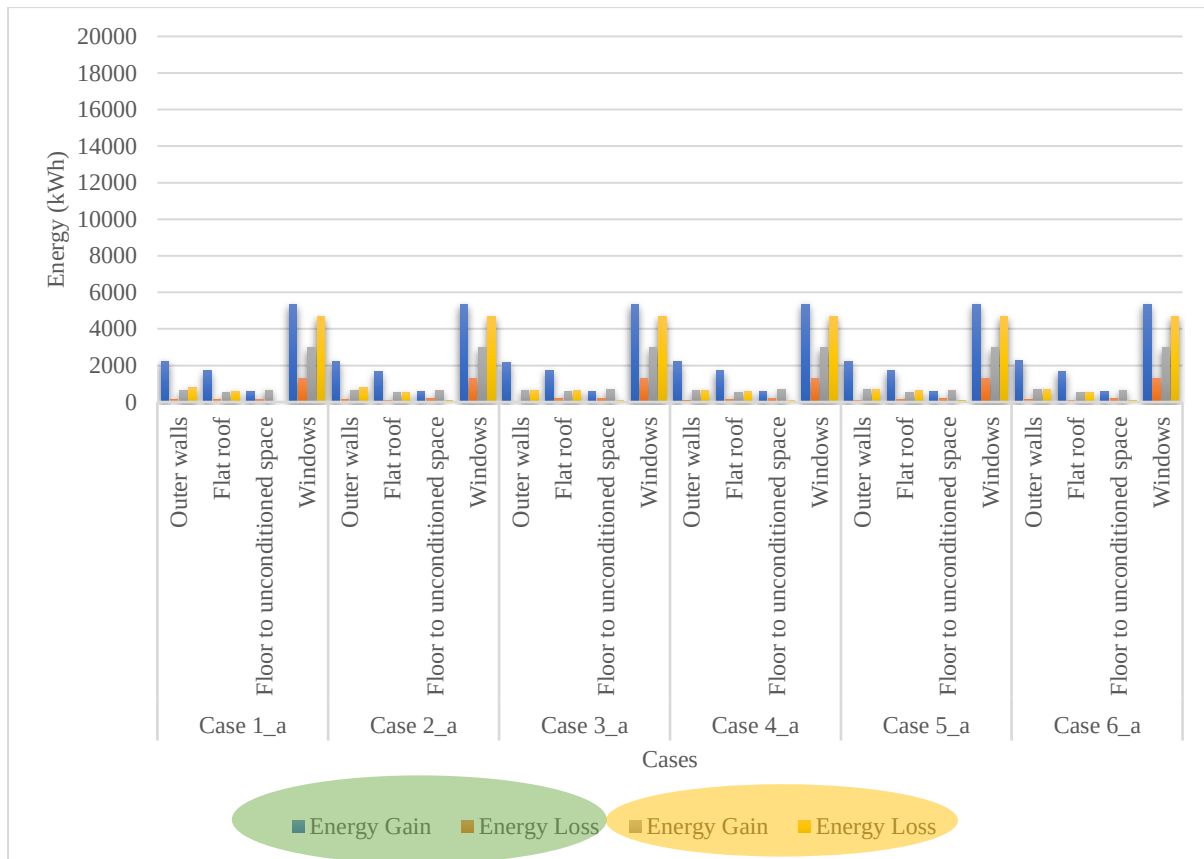


Figure 36: Energy gain/loss by a component of insulated building

Figure 37 and 38 illustrates the thermal comfort and indoor air quality of insulated buildings and uninsulated building, categorized into four classes based on EN15251:2006 standards[11]. Each class is characterized by unique properties that contribute to the assessment of thermal comfort and indoor air quality within the building environment. Here we not got favourable results due to the design and recommended temperature are higher than what set for simulation and therefore cooling demand is also high.

Case 1/Zone 1: Quality of indoor environment in % of time in four categories (prEN 15251:2006)

Percentage	12	19	7	63
Thermal environment	I	II	III	IV
Percentage	5	16	42	37
Indoor air quality	I	II	III	IV

Figure 37: Quality of indoor environment of uninsulated buildings (Bareilly)

Percentage	8	14	7	70
Thermal environment	I	II	III	IV
Percentage	11	42	28	20
Indoor air quality	I	II	III	IV

Figure 38: Quality of indoor environment of insulated buildings (Bareilly)

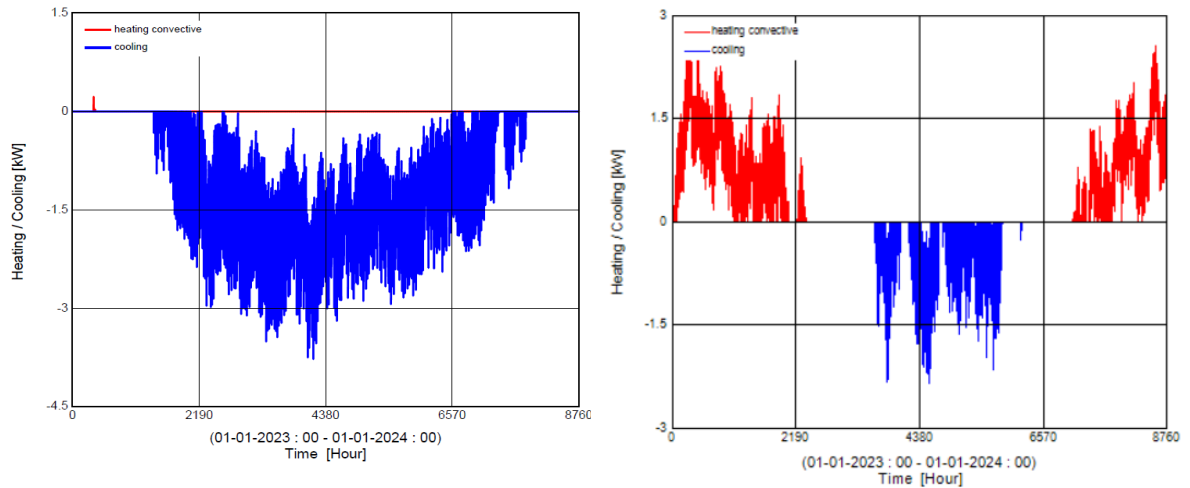


Figure 39: Representation of hourly heating and cooling in an insulated family house (Left: Bareilly and Right: Budapest)

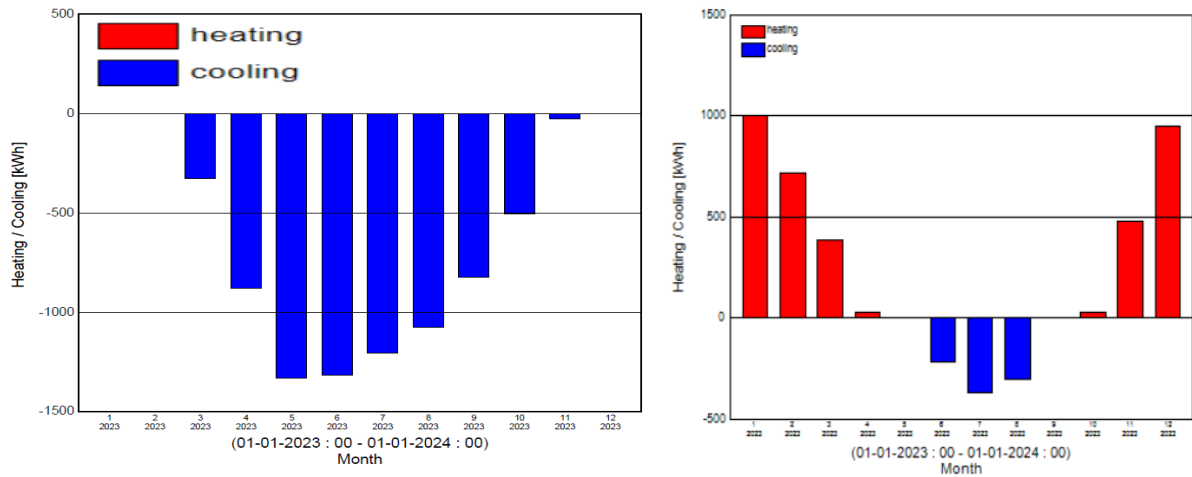


Figure 40: Monthly energy representation of cooling and heating in the insulated family house (left: Bareilly, right: Budapest)

Figures 39 and 40 offer a comprehensive overview of the annual heating and cooling needs for insulated structures in Bareilly and Budapest. The visual representation highlights a heating requirement in Budapest from November to March, totalling 2 kWh, while Bareilly experiences no heating demand in this period. Significantly, the data covers the timeframes from 0 hr to 2200 hr and from 6570 hr to around 8760 hr for the heating season in Budapest. Conversely, Budapest's cooling season spans from June to the end of August (4000 hr to 5500 hr), with an energy consumption range of about 2 kWh. In Bareilly, the cooling demand persists for eight months, with an average consumption of 4 kWh. Figure 35 provides a visual breakdown of the monthly energy usage in an insulated building.

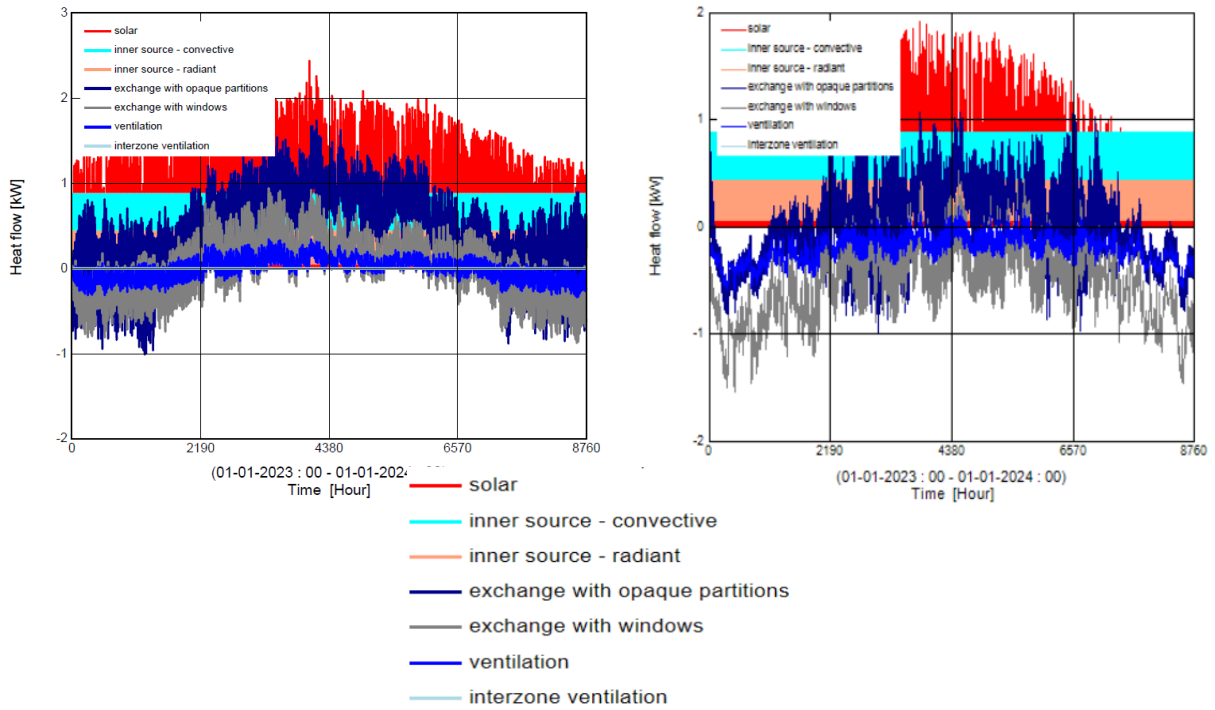


Figure 41: Hourly heat flows in an insulated building (left: Bareilly, right: Budapest)

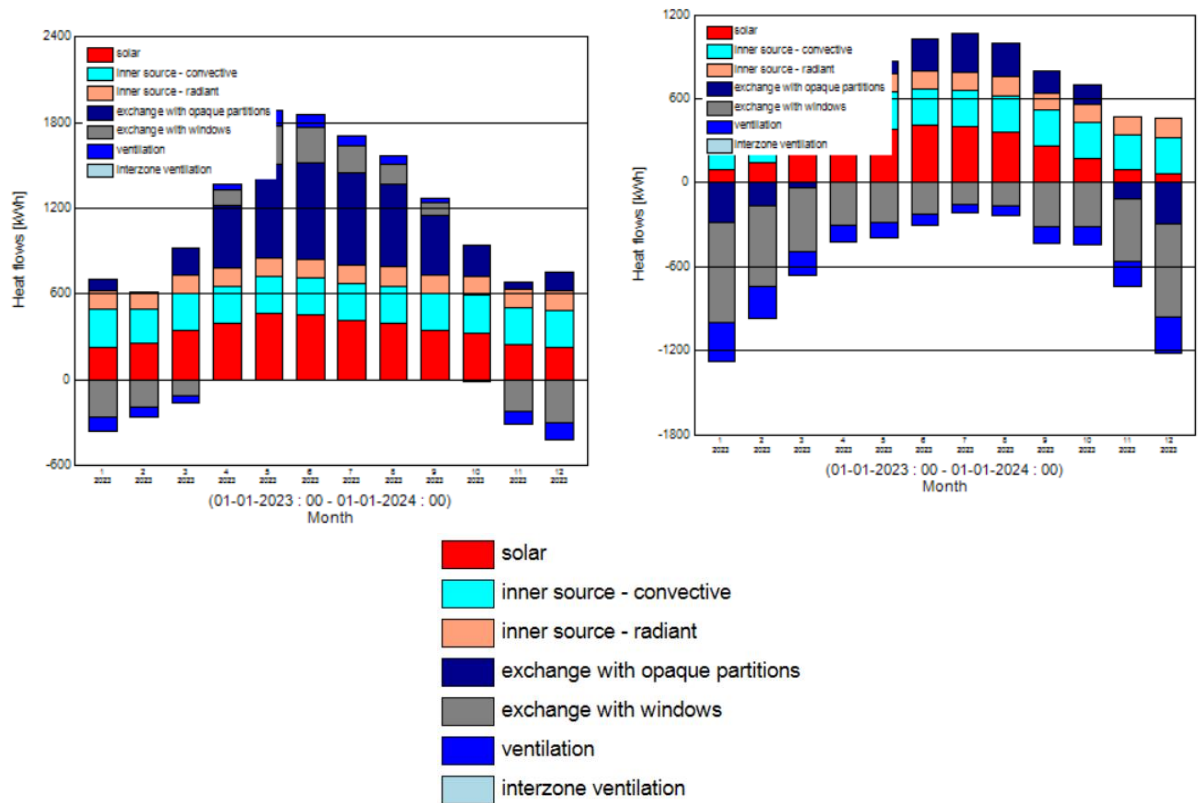
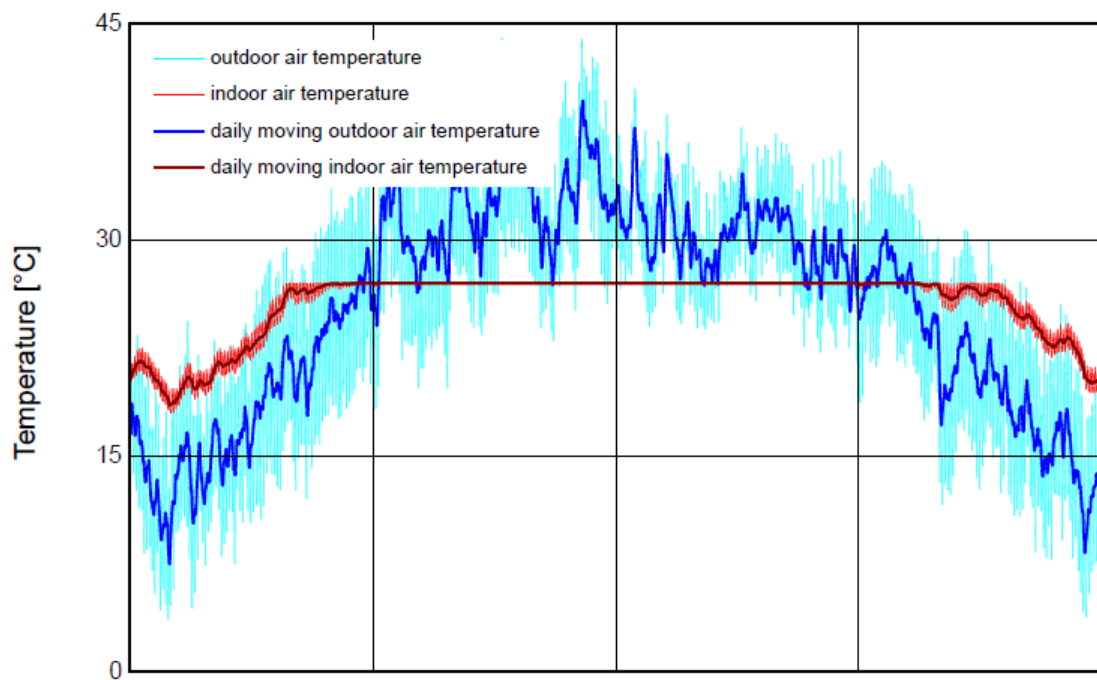


Figure 42: Monthly heat flows in an insulated family house (left: Bareilly, right: Budapest)



Figur43: Overheating climate

4.3 Comparison of two insulated and Uninsulated building in two different geographic location.

In this comprehensive comparative study, we conducted two primary comparisons: one based on different geographic locations and the other on insulated versus uninsulated buildings. While the building modelled in the software appears suitable for the Bareilly location, it proves unsuitable for the Budapest climate when considering energy gain or loss. Table 8 presents the thermal resistance and thermal transmittance values for each layer used in constructing a family house with and without insulation.

Despite a consistent outdoor climate, the interior climate varies based on the materials used. For the geographic comparison, we analyzed six cases, altering building materials for walls, floors, and roofs in two distinct locations. **Figure 45** illustrates the heating and cooling demand of uninsulated building cases, revealing significant variations due to distinct climates. Notably, Case 4 emerged as the most favourable for both locations without insulation, incorporating ACC blocks for the walls and RCC for the slab.

Moving to insulated family houses, **Figure 46** explains the heating and cooling demand. Comparing insulated and uninsulated buildings, we observed a remarkable reduction in

energy demand for heating by approximately 99.5% and cooling demand by 55% in the Bareilly zone. In Budapest, the energy demand for heating decreased by 86%, while the cooling demand increased by 48%. These findings underscore the effectiveness of thermal insulation and additional layers in optimizing energy efficiency in diverse climatic conditions.

Table 8: Thermal transmittance and thermal resistance value

Building Component	Un-Insulated		Insulated	
	U-Value	R-Value	U-Value	R-Value
Exterior wall with Solid Brick	1.644	0.438	0.229	4.188
Exterior wall with ACC Block	0.605	1.484	0.215	4.484
Exterior wall with Porotherm	1.501	0.496	0.226	4.246
Floor with RCC	1.345	0.403	0.225	4.11
Slab with Brick	2.556	0.251	0.223	4.339
Slab with RCC	3.85	0.12	0.243	3.969

Case 1/Zone 1: Quality of indoor environment in % of time in four categories (prEN 15251:2006)

Percentage	8	10	7	75
Thermal environment	I	II	III	IV
Percentage	5	19	39	37
Indoor air quality	I	II	III	IV

Case 1/Zone 1: Quality of indoor environment in % of time in four categories (prEN 15251:2006)

Percentage	5	6	3	86
Thermal environment	I	II	III	IV
Percentage	11	45	37	8
Indoor air quality	I	II	III	IV

Figure 44: Quality of indoor environment of Budapest (Top: After Insulation Bottom: Before Insulation)

Figure 44 shows the thermal environment comfort and indoor air quality before and after insulation. The result what we obtained is not favourable because the internal minimum and maximum temperature is used 18 and 25 degrees centigrade. The infiltration Air Exchange rate was set 0.1 1/h for the simulation. The air indoor quality and thermal environment is not only based on temperature but also on the building materials.

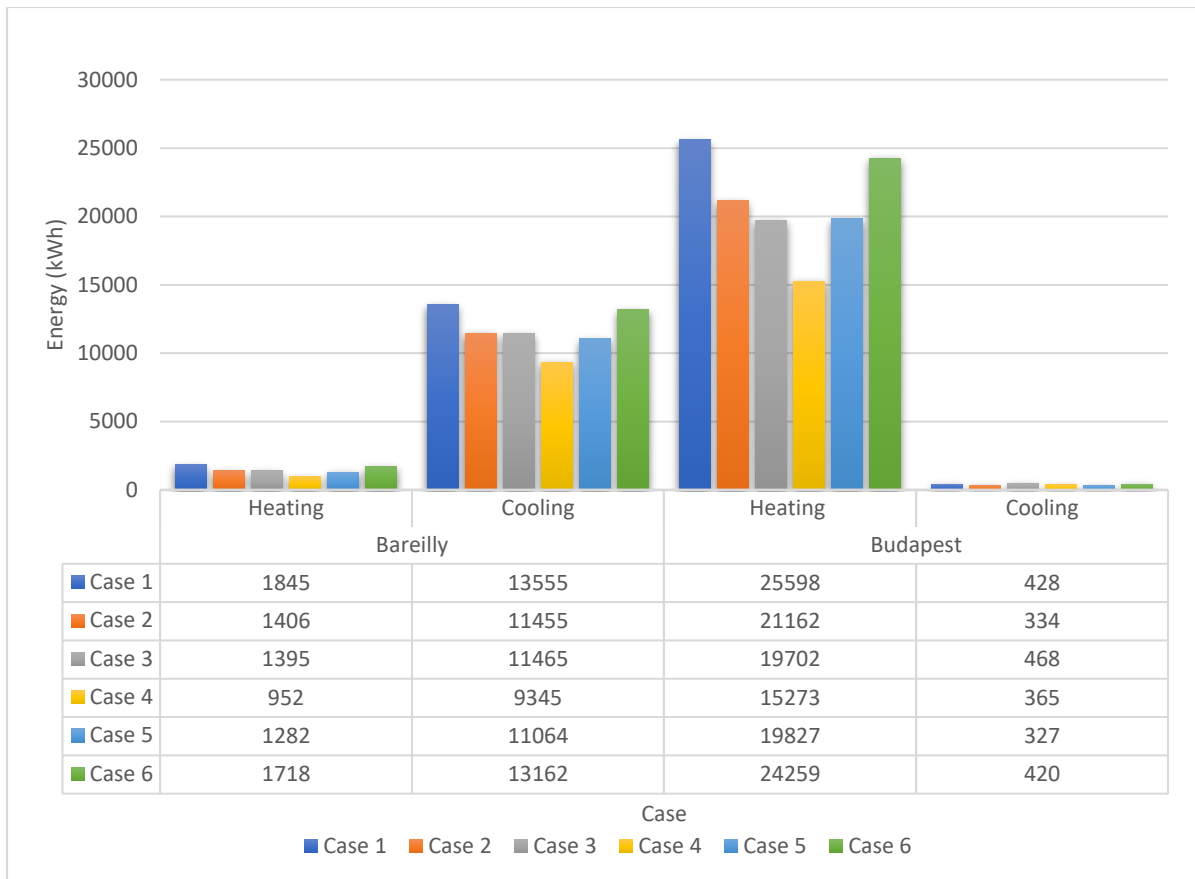


Figure 45: Consumption of Energy for Heating and Cooling of Un-Insulated Structures

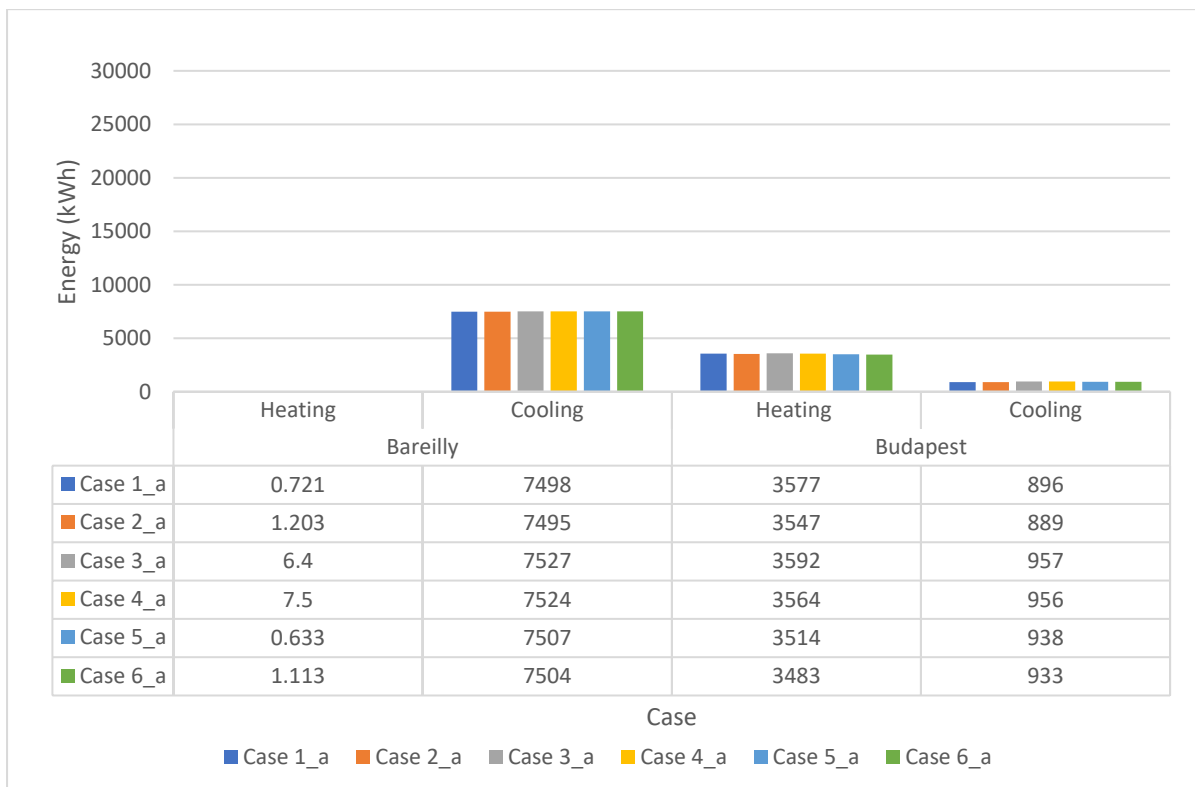


Figure 46: Consumption of Energy for Heating and Cooling of Insulated Structures

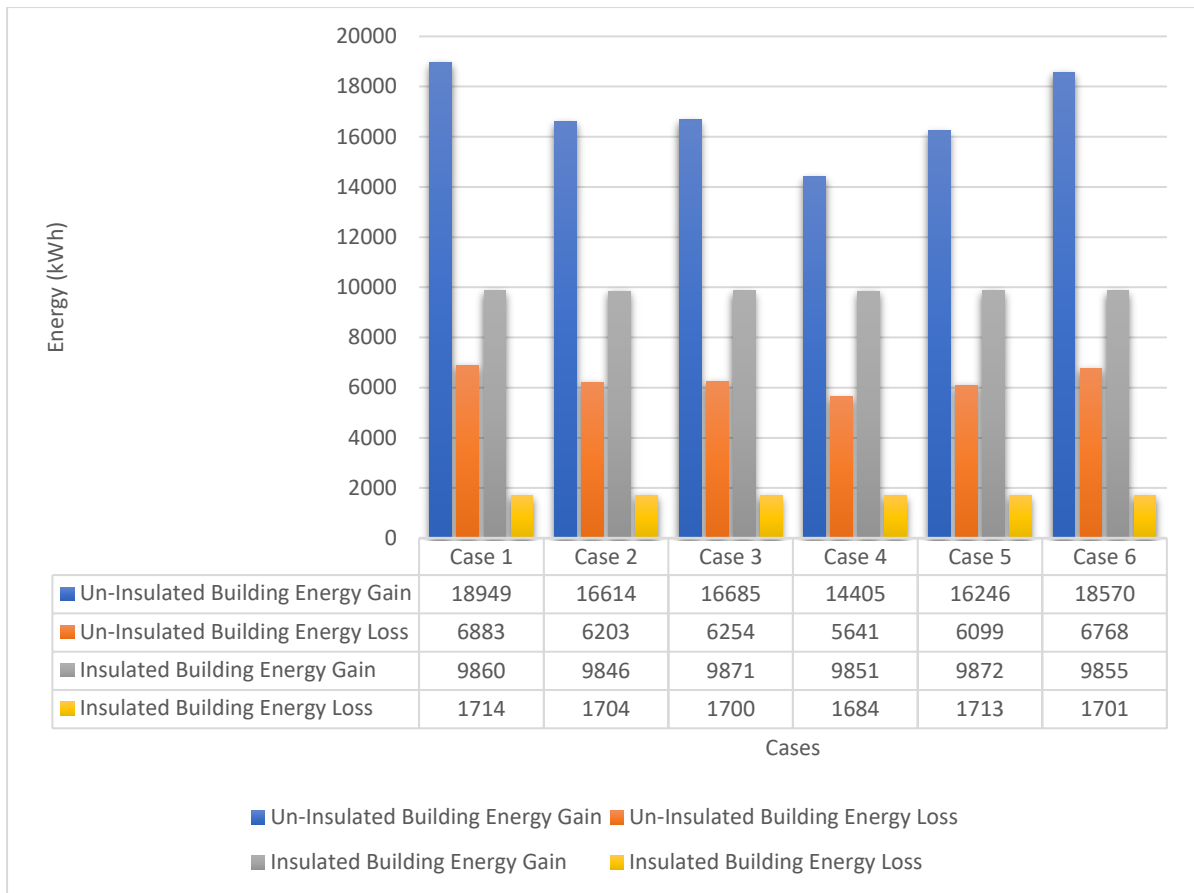


Figure 47: Quantifying Total Energy Fluctuations in Uninsulated and Insulated Buildings in the Bareilly Context

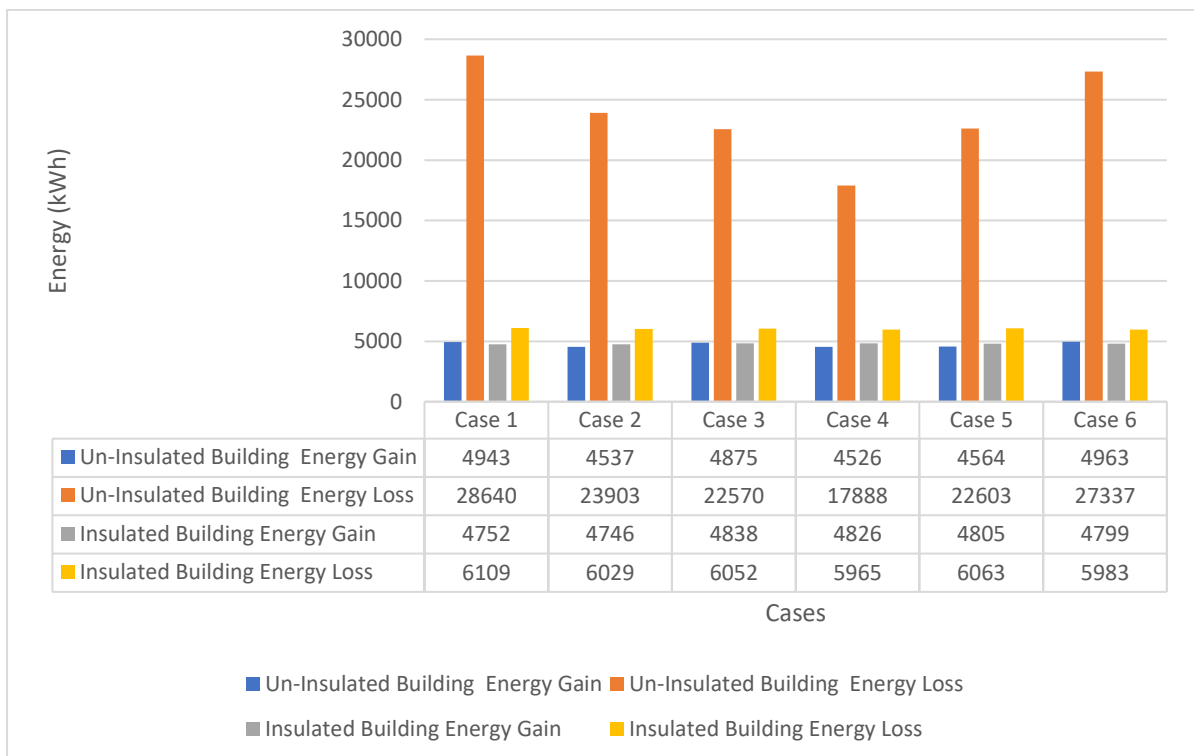


Figure 48: Quantifying Total Energy Fluctuations in Uninsulated and Insulated Buildings in the Budapest Context

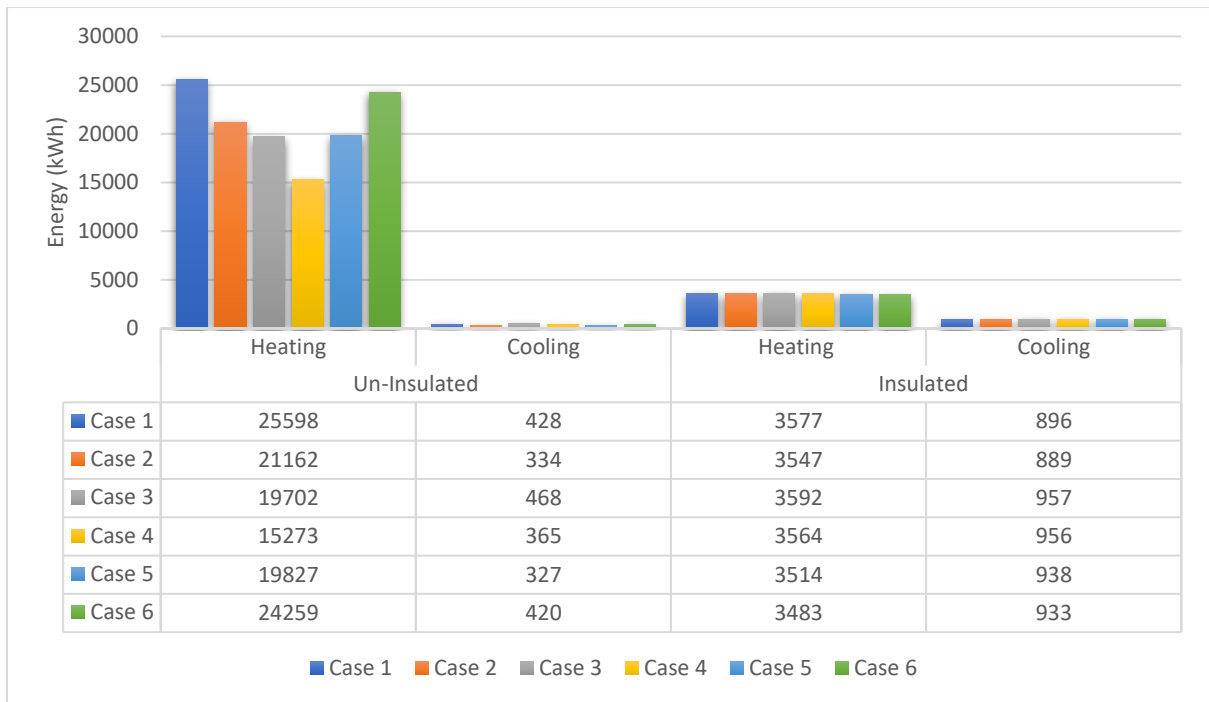


Figure 49: Examining the Differences in the Budapest Zone Between Un-Insulated and Insulated Buildings

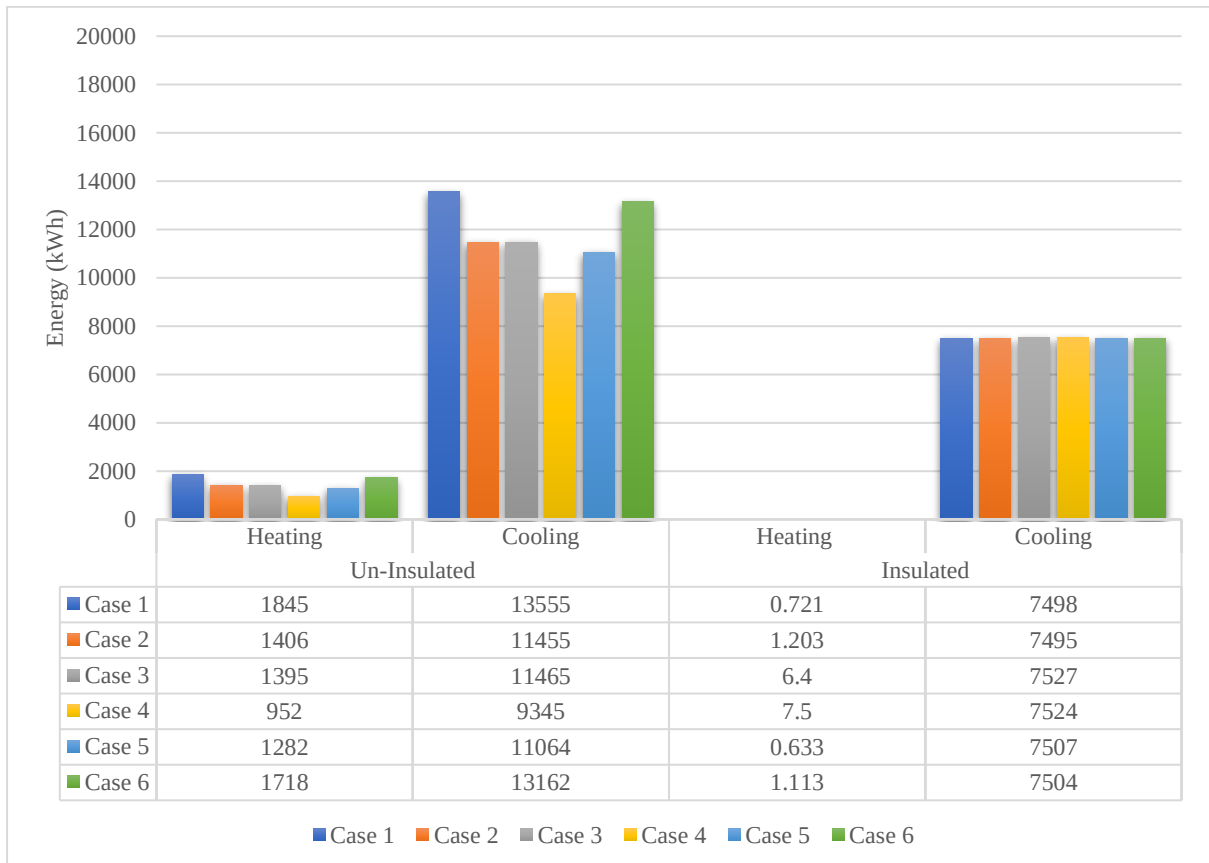


Figure 50: Examining the Differences in the Bareilly Zone Between Un-Insulated and Insulated Buildings

4.1 Analysis of building after increasing infiltration ACH (1/h) from 0.1 to 0.4

Case 1/Zone 1: Quality of indoor environment in % of time in four categories (prEN 15251:2006)

Percentage	7	10	8	75		
Thermal environment	I	II	III	IV		
Percentage	37			21	36	5
Indoor air quality	I			II	III	IV

Case 1/Zone 1: Quality of indoor environment in % of time in four categories (prEN 15251:2006)

Percentage	8	10	7	75
Thermal environment	I	II	III	IV
Percentage	5	19	39	37
Indoor air quality	I	II	III	IV

Figure 51: Indoor thermal environment and Air Quality of Budapest (top: ACH 0.4 1/h and bottom: 0.1 1/h)

Case 1/Zone 1: Quality of indoor environment in % of time in four categories (prEN 15251:2006)

Percentage	12	19	7	63
Thermal environment	I	II	III	IV
Percentage	5	16	42	37
Indoor air quality	I	II	III	IV

Case 1/Zone 1: Quality of indoor environment in % of time in four categories (prEN 15251:2006)

Percentage	12	17	8	63		
Thermal environment	I	II	III	IV		
Percentage	33		25		37	5
Indoor air quality	I		II		III	IV

Figure 52: Indoor thermal environment and Air Quality of Bareilly (top: ACH 0.1 1/h and bottom: 0.4 1/h)

Upon raising the infiltration ACH from 0.1 to 0.4 (1/h)[29], we observed a slight increase in both heating and cooling demands. The primary objective behind this increase in ACH was to introduce more fresh air, thereby reducing the concentration of indoor air pollutants and enhancing overall indoor air quality. Interestingly, there were negligible changes noted in the thermal environment despite the adjustments made. Figures 51 and 52 illustrate about thermal environment and indoor air quality in Bareilly and Budapest for case1.

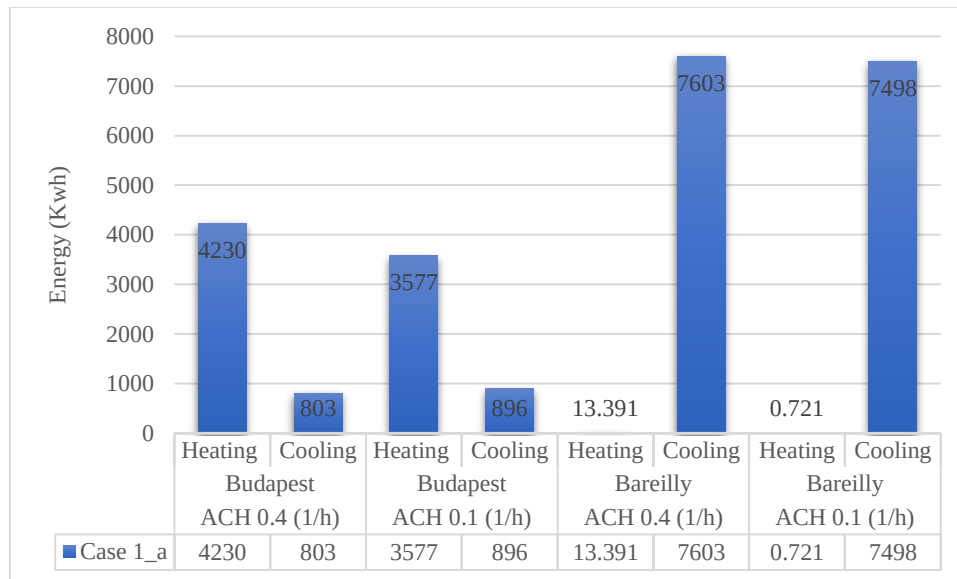


Figure 53: Heating and Cooling demand after changing infiltration air rate

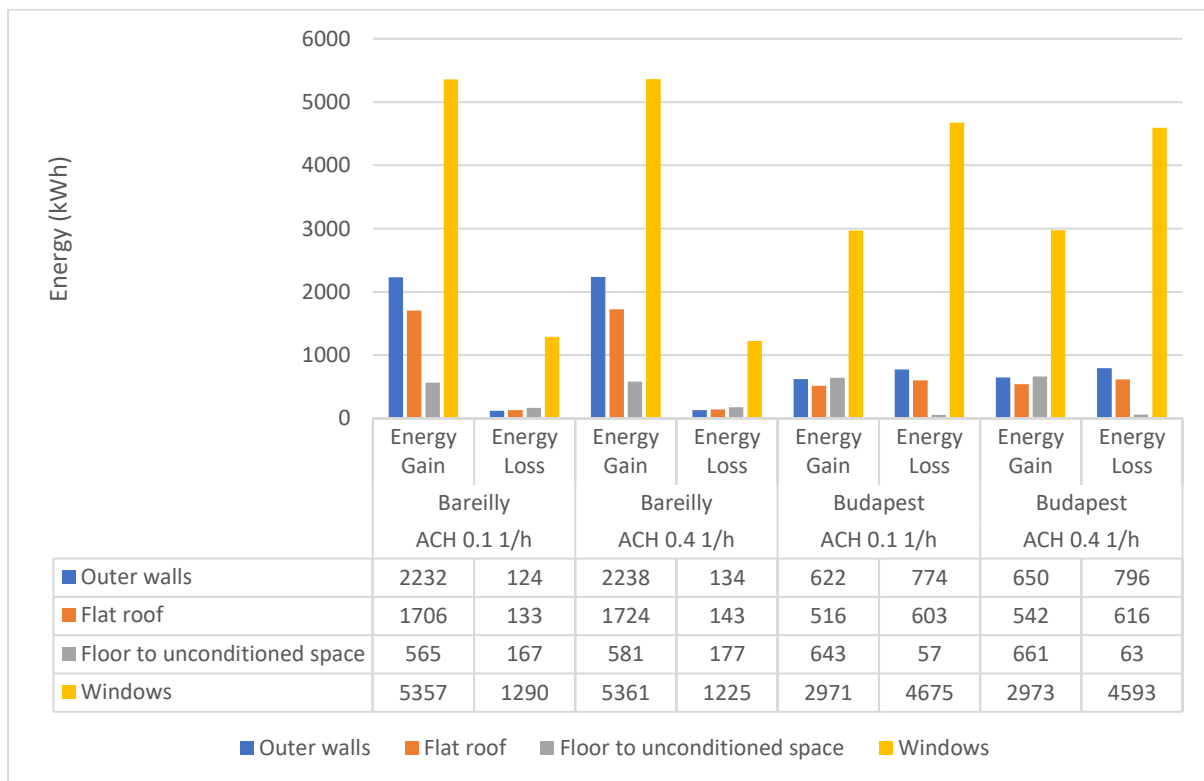


Figure 54: Total Energy gain and loss by component of building after changing Air infiltration rate

Figure 53 visually represents the impact on heating and cooling demand resulting from a change in air infiltration rate (ACH) from 0.1 1/h to 0.4 1/h. The findings indicate a 17% increase in heating demand in Budapest and a 12% increase in Bareilly, along with a decrease in cooling demand in Budapest and an increase in Bareilly. In Figure 54, the total energy fluctuations post the ACH value increase reveal an overall rise in energy gain/loss across all components, except for windows, where it demonstrates a reduction.

5. Conclusion

This research delves into two primary facets: the evaluation of uninsulated and insulated buildings. Examining uninsulated structures, we analyzed six buildings with diverse materials, focusing on a conventional model through Wufi Plus software. The investigation brought to light significant variations in energy gain and loss between Bareilly and Budapest, emphasizing specific components influencing energy consumption. Shifting to insulated buildings, the study highlighted the impact of window choices on energy dynamics across distinct geographic locations. Challenges surfaced in Budapest, where the model, effective in Bareilly, grappled with substantial energy loss and climate disparities. Recommendations for adjustments in layer order and additional layers aimed to enhance suitability in Budapest.

The uniqueness of this research lies in its all-encompassing comparative approach, considering geographic locations and insulation factors. It provides a detailed breakdown of energy dynamics within building components, offering insights into the diverse impacts of construction materials and methods. Emphasizing the significance of thermal insulation and layer modifications for optimal energy efficiency in varied climates, the analysis employs hourly resolution to capture coupled heat and moisture behaviour.

Results indicate that a uniform construction methodology is unsuitable for both locations. The application of thermal insulation and necessary layers in the Bareilly zone led to a remarkable 99% reduction in heating and a 55% decrease in cooling demand, highlighting the potential for significant energy savings in insulated buildings. Moreover, adopting insulated structures can contribute to decreased electricity consumption from mechanical devices. For uninsulated buildings, ACC blocks were identified as optimal for wall construction. In the Budapest climate, adjustments like updating layer orders and increasing thickness in uninsulated buildings are essential. Interestingly, buildings constructed using standard methods proved adaptable to both locations, resulting in an 86% reduction in heating energy when transitioning from traditional to standard methods. The study emphasized the need for adjustments like updating layer orders and increasing thickness in uninsulated buildings in the Budapest climate. The research findings, presented with detailed graphical representations, offer valuable insights for professionals and researchers, highlighting the imperative to optimize energy efficiency in diverse climatic conditions.

The evaluation of the thermal environment indicates that 65% falls within class 4, while the remaining 35% is distributed among classes 1, 2, and 3 for both buildings. In terms of indoor air quality, non-insulated buildings are predominantly categorized as class 2 (42%), whereas insulated buildings are mainly classified as class 3, also comprising 42%. These results offer

valuable insights into the varied impacts of construction methods on energy consumption, thermal conditions, and indoor air quality across different geographical locations. Altering the ACH value from 0.1 to 0.4 1/h shifts indoor quality to 37% in class 1 for Budapest and 33% for Bareilly.

In this study, a comprehensive analysis of energy efficiency was conducted using a randomly selected 3-dimensional building, employing a detailed simulation that considered heat and moisture transfer for individual structural elements. The investigation highlighted variations in energy gain and loss in uninsulated buildings, with specific components playing crucial roles. While insulated buildings proved effective in Bareilly, challenges arose in Budapest, emphasizing the need for layer adjustments. Refining window choices and exploring additional layers emerged as key considerations for optimal performance. Future research directions include addressing thermal bridges, studying microclimatic factors, and comparing refurbishment methods. Overall, the study underscores the pivotal role of insulation and construction materials in optimizing energy efficiency across diverse climatic conditions.

6. Acknowledgement

I first acknowledge our regard to Almighty “GOD” for giving me patience during this research work and the knowledge which I have.

I wish to express my sincere gratitude, respect, and honor to my supervisor Dr. Nagy Balázs and Szagri Dora for their precious time, all guidance, help, support and timely suggestion which has been a source of inspiration during this research project.

I also express my thanks to faculty of Civil Engineering at Budapest university of Technology and Economics for this opportunity.

Finally, I am grateful for the unconditional, spiritual support and sacrifices of my parents without them this could not be done. You have done all what you are supposed to do.

7. Reference

- [1] K. Parker, J. Horowitz, R. Minkin, and T. Arditi, “FOR MEDIA OR OTHER INQUIRIES,” 2022. [Online]. Available: www.pewresearch.org.
- [2] M. Woloszyn, T. Kalamees, M. O. Abadie, M. Steeman, and A. Sasic Kalagasidis, “The effect of combining a relative-humidity-sensitive ventilation system with the moisture-buffering capacity of materials on indoor climate and energy efficiency of buildings,” *Build Environ*, vol. 44, no. 3, pp. 515–524, Mar. 2009, doi: 10.1016/j.buildenv.2008.04.017.
- [3] H. Viitanen *et al.*, “Moisture and bio-deterioration risk of building materials and structures,” *J Build Phys*, vol. 33, no. 3, pp. 201–224, Jan. 2010, doi: 10.1177/1744259109343511.
- [4] J. Toftum, A. S. Jørgensen, and P. O. Fanger, “Upper limits of air humidity for preventing warm respiratory discomfort,” *Energy Build*, vol. 28, no. 1, pp. 15–23, Aug. 1998, doi: 10.1016/S0378-7788(97)00018-2.
- [5] H. Fischer, F. Frühwald, and A. Korjenic, “Ecological comparison of hygrothermally safe floor constructions based on renewable raw materials for multi-storey buildings,” *Journal of Building Engineering*, vol. 57, p. 104899, Oct. 2022, doi: 10.1016/J.JOBE.2022.104899.
- [6] “<https://cea.nic.in/dashboard/?lang=en>.”
- [7] “IEA – International Energy Agency.” Accessed: Oct. 27, 2023. [Online]. Available: <https://www.iea.org/>
- [8] A. M. Papadopoulos, “Forty years of regulations on the thermal performance of the building envelope in Europe: Achievements, perspectives and challenges,” *Energy Build*, vol. 127, pp. 942–952, Sep. 2016, doi: 10.1016/J.ENBUILD.2016.06.051.
- [9] N. R. Martins and G. Carrilho da Graça, “Impact of PM2.5 in indoor urban environments: A review,” *Sustain Cities Soc*, vol. 42, pp. 259–275, Oct. 2018, doi: 10.1016/J.SCS.2018.07.011.
- [10] “<https://www.statista.com/topics/8881/emissions-in-india/#topicOverview>.”
- [11] - Bsi, “prEN 15251 - 51_e_stf,” 2006.
- [12] D. Szagri and B. Nagy, “The Effect of Thermal Insulation and User Behaviour on Energy Consumption and Comfort of Residential Houses.”
- [13] D. Szagri, B. Nagy, E. Csanaky, and Z. Szalay, “iiSBE Forum of Young Researchers in Sustainable Building 2019 Decision-Support Tools and Assessment Methods for Sustainable Built Environment Investigating Overheating of Nursing Homes to Support Heatwave Risk Analysis Methodology”.
- [14] D. Szagri and B. Nagy, “Building energy analysis of an industrial hall based on dynamic simulations,” *International Review of Applied Sciences and Engineering*, vol. 9, no. 2, pp. 145–151, Dec. 2018, doi: 10.1556/1848.2018.9.2.10.
- [15] P. Jaboyedoff, “ENERGY EFFICIENT BUILDING ENVELOPE & VENTILATION STRATEGIES FOR MULTI-STOREY RESIDENTIAL BUILDINGS IN INDIA.”
- [16] “Thermal Insulation of Buildings for Energy Efficiency”.

- [17] “What is the difference between an RC slab and an RB slab in construction? - Quora.” Accessed: Nov. 05, 2023. [Online]. Available: <https://www.quora.com/What-is-the-difference-between-an-RC-slab-and-an-RB-slab-in-construction>
- [18] “Premium Photo | Home roof under construction with iron bar frame reinforcement materials and equipment side view.” Accessed: Oct. 20, 2023. [Online]. Available: https://www.freepik.com/premium-photo/home-roof-construction-with-iron-bar-frame-reinforcement-materials-equipment-side-view_32200567.htm
- [19] “<https://law.resource.org/pub/in/bis/S03/is.1077.1992.pdf>.”
- [20] “Bareilly Weather & Climate | Temperature & Weather By Month - Climate-Data.org.” Accessed: Oct. 23, 2022. [Online]. Available: <https://en.climate-data.org/asia/india/uttar-pradesh/bareilly-2852/>
- [21] “Bareilly climate: weather by month, temperature, precipitation, when to go.” Accessed: Oct. 23, 2022. [Online]. Available: <https://www.climatestotravel.com/climate/india/bareilly>
- [22] “Budapest Weather & Climate | Temperature & Weather By Month - Climate-Data.org.” Accessed: Oct. 23, 2022. [Online]. Available: <https://en.climate-data.org/europe/hungary/budapest/budapest-1218/>
- [23] “CEN Enquiry version prEN 15026_CHS_HF_HK 12_10_22”.
- [24] “(PDF) Verfahren zur ein-und zweidimensionalen Berechnung des gekoppelten Wärme-und Feuchtetransports in Bauteilen mit einfachen Kennwerten. Ph.D. thesis, Universität Stuttgart.” Accessed: Nov. 05, 2023. [Online]. Available: https://www.researchgate.net/publication/260028324_Verfahren_zur_ein-und_zweidimensionalen_Berechnung_des_gekoppelten_Wärme-und_Feuchtetransports_in_Bauteilen_mit_einfachen_Kennwerten_PhD_thesis_Universitat_Stuttgart
- [25] F. Antretter, F. Sauer, T. Schöpfer, and A. Holm, “VALIDATION OF A HYGROTHERMAL WHOLE BUILDING SIMULATION 1 SOFTWARE 2 3”.
- [26] “Wufi Manual”.
- [27] “What is WUFI®? | WUFI (en).” Accessed: Nov. 01, 2022. [Online]. Available: <https://wufi.de/en/software/what-is-wufi/>
- [28] “Flow chart of the hygrothermal modelling process. | Download Scientific Diagram.” Accessed: Nov. 05, 2023. [Online]. Available: https://www.researchgate.net/figure/Flow-chart-of-the-hygrothermal-modelling-process_fig2_355809230
- [29] “Számítási módszer referenciaértékei Éghajlati adatok”.