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Abstract

Buildings are responsible for 40 percent of energy consumption in cities and cities are responsible for 60 to 80 percent of the total energy consumption in the world. Besides energy consumption in the industrial market which has complex dynamics to investigate, residential buildings have a big piece of the pie in this share. To avoid the catastrophic effects of climate change and depletion of sources, energy demand and correspondingly energy consumption in cities should be controlled immediately by every energy consumer. In this matter, the control of energy demand depends principally on the actions of the users. Evaluating the social science behind energy consumption is not the study area of this research but the impact of adaptive behaviours to control indoor comfort are main objectives. This study goals to examine the effect of occupant behavior through DesignBuilder with hypothetical and probabilistic scenarios which are configurations of Occupancy, Heating, Cooling, DHW, Equipment and Lighting schedules and setpoints. Three different building typologies from 3 different cities and climates` building energy performance will be analyzed through the combination of two other variables: thermal condition of the buildings and user behavior. The user behaviors are grouped into two as economic and wasteful. In the end, the comparative results of the scenarios were analyzed. The final comparison analysis confirms the assertion of the study that user behavior effects the energy demand directly proportional; wasteful occupant has the highest energy demand while the scenarios based on the Spanish technical code for energy savings has the optimal and economic scenarios have the lowest. The analysis of the study leads to an untouched area of study to enlarge the scale and examine the impact of occupant behavior at low energy districts and cities to prevent the negative effects of increased urban energy consumption.

Keywords: Building Energy Simulation, Energy Demand, Energy Efficiency in Buildings, Low Energy Districts, Occupant Behaviour

Ruken Karakus

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Table of Contents

ACKNOWLEDGEMENTS III

ABSTRACT V

TABLE OF CONTENTS VII

LIST OF TABLES X

LIST OF FIGURES XI

LIST OF ABBREVIATIONS XII

1 INTRODUCTION 1

1.1 BACKGROUND 2

1.1.1 European Strategies on Energy Efficiency in Buildings 2

1.2 PROBLEM STATEMENT, MOTIVATION AND OBJECTIVES 4

1.2.1 User Behavior on Energy Consumption 4

2 THE ANALYSIS 7

2.1 INFLUENCE OF USER BEHAVIOR 7

2.1.1 Economical 9

2.1.2 Political 9

2.1.3 Cultural 9

2.1.4 Sociability 10

2.1.5 Occupancy 10

2.1.6 Comfort Satisfaction 10

2.1.7 Personal Preferences 10

2.1.8 Psychological Factors 11

2.1.9 Environmental Awareness 11

2.1.10 Lifestyle 11

2.2 BUILDING ENERGY SIMULATION TOOLS 12

2.3 GAP BETWEEN ENERGY SIMULATION AND OPERATION USE 17

2.4 REVIEW OF RELATED CASES 17

2.4.1 Bilbao, IDOM Case ... 17
2.4.2 Copenhagen Case: Effect of thermostat and window opening occupant behavior models on energy use in homes [12]: ... 18
2.4.3 Istanbul, Dormitory Case: The Impact of User Behavior on Energy Consumption - A Case Study of Kilyos Saritepe Campus Dormitory through Hong and Lin grouping methodology [28]: ... 18
2.4.4 Iran, Residential Case: A study of the impact of occupant behaviors on the energy performance of building envelopes using occupants' data [43]: ... 19

3 METHODOLOGY ... 21

3.1 WHY DESIGN-BUILDER? ... 21
3.2 DATA INPUTS ... 21
3.2.1 Location and Climate ... 21
3.2.2 Settlement and Building ... 22
3.2.3 Construction Materials ... 22
3.2.4 Energy Demand Settings ... 22
3.2.5 Occupancy and Use ... 23
3.3 QUANTIFICATION ... 24
3.3.1 Heating and Cooling ... 24
3.3.2 DHW, Domestic Hot Water ... 24
3.3.3 Equipment & Lighting ... 24

4 CASE STUDIES ... 25

4.1 LIMITATIONS ... 25
4.2 ASSUMPTIONS ... 26
4.3 LOCATIONS ... 26
4.3.1 Location 1: San Sebastian, Basque Country, Spain ... 27
4.3.2 Location 2: Brussels, Belgium ... 28
4.3.3 Location 3: Istanbul, Turkey ... 28
4.4 BUILDINGS ... 29
4.4.1 Building 1: Multi-Storey Residential building from San Sebastian, Basque Country ... 29
4.4.2 Building 2: Single-Family House from Brussels ... 31

4.4.3 Building 3: Attached Apartment Building from Istanbul *33*
4.5 SCENARIOS 36
4.5.1 Scenario Stories *36*
4.5.2 Scenario Tables *38*
4.6 RESULTS 43
4.6.1 Monthly Results *44*
4.6.2 Annual Comparison According to Countries and Building Typologies *45*
4.6.3 Annual Comparison According to the Scenarios *48*
4.7 SHARE 49
5 CONCLUSIONS & DISCUSSION **51**
5.1 RECOMMENDATIONS AND FUTURE STUDY 53
5.1.1 A Real Life-Occupant Survey Comparison *53*
BIBLIOGRAPHY **55**
APPENDIX **63**

List of Tables

Table 1: Comparison Table of BES Tools (Author)..15
Table 2 Assessment of Literature Review Studies (Author).................................20
Table 3 Building properties Low Thermal Quality (Author)...................................30
Table 4 Building properties Optimum Thermal Quality (Author)...........................31
Table 5 Building_2 Properties Existing State (Author)..31
Table 6 Building_2 Properties Optimum state (Author)..32
Table 7 Building_2 Properties Advanced Refurbishment (Author).......................32
Table 8 Optimal U-values according to TS 825 [67]..33
Table 9 Building_3 Properties Existing (Author)...34
Table 10 Building_3 Properties Low (Author)...35
Table 11 Building_3 Properties High (Author)...35
Table 12 San Sebastian Base Scenario from CTE, `standard users`, Economic and Wasteful Scenarios (Author)..38
Table 13 Brussels Base Scenario (Author)...40
Table 14 Istanbul Base Scenario (Author)..41

List of Figures

Figure 1 Review Roadmap (Author)... 2
Figure 2:Subjective Internal Factors on User Behavior (Author)............................ 8
Figure 3 Adaptive and non-adaptive behaviour influencing the energy consumption [16]... 9
Figure 4 Individual Mean Time Use [26].. 12
Figure 5 Comparison between the standard ASHRAE Occupancy profile and Stochastic occupancy schedules [16]... 17
Figure 6 Map of Case Study Countries (Author).. 27
Figure 7 Building_1 [60] 30
Figure 8 Building_2 [62] 31
Figure 9 Building_3 [65] 34
Figure 10 Building 3 Ground Floor Plan [65] 34
Figure 11: Interaction Map of the subtopics (Author)... 37
Figure 12: Combination Matrix (Author) 38
Figure 13 Monthly Heating Demand 44
Figure 14 Monthly Cooling Demand... 45
Figure 15 Scenario Results for San Sebastian, Multi-Storey Building 46
Figure 16 Scenario Results for Attached Apartment Building, Istanbul 47
Figure 17 Scenario Results for Single-Family House, Brussels.......................... 47
Figure 18 Comparison according to the scenarios Economic and Wasteful...... 48
Figure 19 Energy Demands of Heating, Cooling, Equipment & Lighting and Domestic Hot Water (kWh/m²) 49
Figure 20 The deviation between the two sets of simulation 50
Figure 21 Average Demand of Cooling and Heating between Base, Economic and Wasteful scenarios.. 50
Figure 22 Total Demand in an Ascending Array 63

List of Abbreviations

Abbreviation	Definition
CO2	Carbon dioxide
DB	Design Builder
DHW	Domestic Hot Water
HVAC	Heating, Ventilation and Air Conditioning
BIM	Building Information Modelling
BREEAM	Building Research Establishment Environmental Assessment Method
LEED	Leadership in Energy and Environmental Design
Cfb	Temperate oceanic climate
ACH	Air changes per hour
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning
CTE	Engineers Spanish Technical Building Code
BES	Building Energy Simulation
U-Value	Thermal Transmittance
GUI	Graphical User Interface
API	Application Program Interface
HDD	Heating Degree Days
CDD	Cooling Degree Days
Csa	Hot summer Mediterranean Climate
2D	Two-dimensional space
3D	Three-dimensional space
IFC	Industry Foundation Classes
CAD	Computer aided design
DOE	U.S. Department of Energy
LCA	Life Cycle Assessment

EEA	European Environment Agency
EPBD	European Performance of Buildings Directive
BEP	Building Energy Performance
TABULA	Typology Approach for Building Stock Energy Assessment
BEST	Building Energy Software Tool
EU	European Union
GHG	Greenhouse gases
ICT	Information and Communications Technology
IEA	International Energy Agency
EJ	Energy Joule
nZEB	Nearly Zero Energy Buildings
SRI	Smart Readiness Indicator
UNDP	United Nations Development Programme
WorldGBC	World Green Building Council

1 Introduction

As smart cities begin to become dehumanized realms and human behavioural data is neglected, the place of humans in the overall concept of energy transition in cities has become a fading phenomenon. Technology-driven cities hardly consider the human factor while conducting future simulations to evaluate the environmental or economical estimations. To create future sustainable urban areas, before focusing on creating new smart systems; the resource, energy needs of a city and providing a superior quality of life for its residents should be carefully understood while planning together with the residents. Technology is seen as the principal actor in smart cities, not humans, so the data collection from ICT technologies depends only on the previous machine learning algorithms but neglects the unpredictable nature of human behaviour [1]. While technological solutions have proven to save energy, these solutions started to leave the anthropogenic factors behind. Energy consumption or waste of resources is not only built upon technical reasons but also sociological, psychological, cultural reasons. This study aims to prove that technological assessment systems such as simulations linked only to deterministic data may be inadequate. Thus, the study scale is taken at the building level due to the sufficient data and improved quality of building simulations tools even though the accuracy level of these tools is debatable, compared to the real-life applications. Furthermore, the research can be carried out at the district and urban level.

To ease the understanding of the study structure, Figure 1 explains the roadmap for reviewers. The diagram summarizes the phases of the research study and structures the understanding.

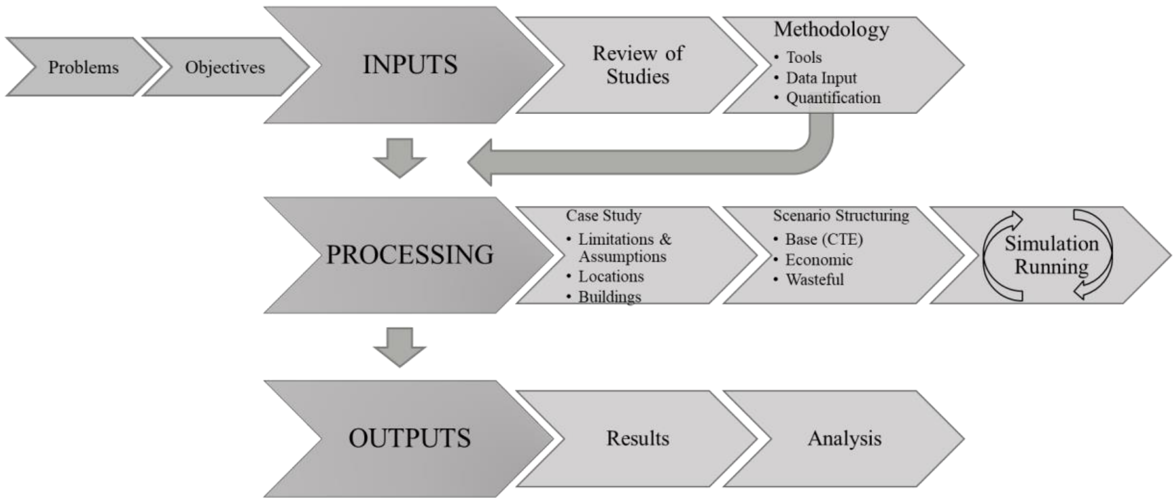


Figure 1 Review Roadmap (Author)

1.1 Background

According to the data from UNDP Sustainable Development Goals 17 [2], Sustainable Cities and Communities; by 2050 over 60% of the population will live in the cities; this rapid growth will cause the cities to be the main contributor of climate change.

Cities cause 60 to 80 percent energy consumption while covering only 3 percent of the land and accountable for 70 percent of the carbon emissions in total. In the coming decades, it has been predicted that 90 percent of urban growth will take place in developing countries [2], raising the question of how this growth will perform while developing countries still lack access to key rural services countrywide such as the right to shelter and preventing energy poverty. While Europe has explored methods to address urban issues, by strengthening urban areas, buildings, and quality of life; developing countries still have a long way to go.

1.1.1 European Strategies on Energy Efficiency in Buildings

Energy consumption in buildings is also a substantial source of GHG emissions. European Union has ongoing policies on climate and energy policies and European Union`s climate-energy goals suggest sustainable construction and materials for lower emissions and is climate resilient [3]. Built environment handles 40% [4], [5] of energy consumption and 36% of CO_2 emissions in the EU [5], thus it has a set of targets to achieve a climate-neutral Europe by 2050 under the European Green Deal policy [3]. Horizon 2020 had been promoting the initiatives to achieve Nearly Zero Energy Buildings and providing funding for energy efficiency and renovation projects. As stated by European Commission by 2017, Europe has already achieved their 2020 energy efficiency in buildings target by decreasing the annual consumption by 20% [6]- [7]. As Horizon2020 was aiming 20%, by 2030 the cut in energy consumption is aimed to be by 32,5% [7].

Policies as European Green Deal have suggestions to provide energy efficiency in buildings in Europe, which are not obligatory but to achieve zero energy buildings recommended by EPBD [8]. EU has over 220 million building stock which has been built before 2001 with an 85% rate of the total building stock and this amount will be remain standing by 2050 [5]. Renovation of these buildings by 2050 was affirmed as a key initiative of the European Green Deal, unfortunately, only 1% of the buildings can go under energy-efficient renovation, while achieving these objectives are essential till 2050 [9]. *“A Renovation Wave for Europe-Greening our buildings, creating jobs and improving lives (COM (2020) 662)”* was published by European Commission aiming to double the energy renovation savings in the next ten years [5], [9]. This energy-efficient renovation movement will not only decrease the energy consumption, but decrease the energy bills, fight against energy poverty as a social-inclusive initiative and decarbonize Europe [5].

As 2020 was a key year for being the closure date for many directives, policies, and initiative it had plenty of data to evaluate the current situations and take further actions. A Guidebook to European Building Policy was published in 2020 to be a guide for the current building situation sharing the Key Legislation and Initiatives. As Europe aims to improve the quality of buildings; it had multiple legislation and proposals such as improving the structural quality of buildings. Since it has been intended to retrofit buildings with Smart Readiness Indicator (SRI) which will enable the end-user to understand the services that they can deliver to raise awareness in the building sector. Buildings should function as highly efficient micro-energy hubs where consumptions, production and storage are done while supplying the energy through a flexible and efficient system [10]. This guidebook also suggests that the renovation of the buildings should be done accordingly to the needs of the occupants and its use [10] during the time that the occupants should manage their behavioural patterns to provide less consumption.

1.2 Problem Statement, Motivation and Objectives

The problem to be focused on is to show the influence of occupant behaviour on energy demand at residential buildings. The case study analysis is made through hypothetical scenarios, without empirical and on-site analysis since the chief goal is to show how the different behavioural patterns affect energy consumption and that responsible acts on this matter can be provided as occupants. Since residential buildings are where human behaviour can show varieties unlike commercial or public areas; the free will of the occupants should not be neglected as it had been in the traditional ways of building energy simulation modellings. As D`Oca et al. [11] stated deterministic approaches at building energy simulation depends on fixed schedules and average numerical data.

The study will be carried out by making the comparison of probabilistic theoretical scenarios; analyzing each scenario with different behavioural patterns of the occupants will show how daily life choices affects the increased energy consumption in cities. Building simulation tools give numerical data for each simulation, through DesignBuilder outcomes analysis and synthesis will be made.

Objectives to be achieved:

- Comparison and analysis of human behavioural pattern`s effects through building simulation tool DesignBuilder. Buildings to be assessed are real-life buildings with the existing construction and material data.
- Affirming occupant`s behaviour as a reason for energy consumption and identifying the common patterns affecting heating, cooling, DHW and appliances & lighting consumption.
- Mentioning how the European strategies work as control mechanisms on the orientation of citizens/occupants at cities.
- Evaluating the outcomes and proposing future improvements-recommendations.

1.2.1 User Behavior on Energy Consumption

While having the biggest percentage of energy consumption in cities; buildings are a direct target to achieve low energy districts, cities, and smart cities. In this meaning, user behaviour has a considerable amount of effect on energy consumption in buildings.

As residents of the buildings, it is hard to be aware of how human behavioural patterns play an important role. By comparing different scenarios, energy simulation tools enable to understand through different scenarios, how daily life choices coming from cultural differences or personal tendencies. Human behavioural patterns have a lot to explore in the background with the psychological, sociological, socio-economical and societal reasons. Unfortunately, building energy simulation tools can only assess the numerical data and neglects the reasons behind this, while newly developed smart technologies at home aim to address this issue. According to the review of D`Oca et al. [11]; previous research from Marchio and Rabl 1991; Andersen 2012; Emery and Kippenhan 2006 [11] state that uncertainties in simulations of energy consumption in dwellings the difference between simulation and real-life can extend to 300% in extreme cases. From a different perspective, occupants are more likely to feel comfortable with personalized energy systems rather than centralized systems that they cannot control [11].

2 The Analysis

Multiple inputs are affecting the energy demand and consumption of a building as well as the occupant`s behaviour. World Green Building Council (WorldGBC) works on the intersection between the energy demand, emissions, and human factor including the key building elements as indoor air quality, lighting quality, energy use, employee sick days and worker productivity [12]. Global Status Report 2017 [12] states that human factors are affecting the energy use in buildings a lot through the occupant choices and their behaviour in the buildings. Unlike European Union, countries like China are promoting occupant friendly technologies and building attributes to make energy savings mandatory requirements to the building occupants [12]. This might be hard to achieve in European Union because of the prevention of human free will that`s why the EU aims smart controls and meters at homes to achieve this. According to the analysis of the International Energy Agency (IEA) [4]; it is possible to save 230 EJ in cumulative energy savings by 2040 through smart controls and connected devices; decreasing the energy consumption in buildings 10% globally, where those savings will allow reduction of carbon intensity [12]. Repeatedly, the same report affirms that approximately 17% of the building final energy consumption is due to the activity which represents the changes in energy use from human factors [12]. Alternatively, European Commission has many initiatives, funding and projects to support energy efficiency in buildings and BUILD UP are one of them. This initiative was founded in 2009 by the EU to execute the Energy Performance of Buildings Directive (EPBD) [8] and gives the possibility to encourage the countries, cities and companies on this matter [13].

2.1 Influence of User Behavior

User behaviour is affected by various external and internal reasons. Economics, politics, country regulations, technical issues, climate are the external reasons that affect the user behaviour and on which the occupant does not have an influence. However, many internal variables only depend on the occupants and to control energy consumption and factors should be understood carefully. Tam et. al. [14] highlight a principal existing gap between the predicted design stage energy consumption and the operation phase energy consumption, by stating that it is commonly over twice the energy. Tam et.al. [14] proceed with the statements that buildings are complex systems affected by many variables; as their physical characteristics, technical systems, equipment, occupant behaviours etc. Previous studies confirm that there is a huge relation between occupants' behaviour and energy consumption in buildings [11], [14]. Occupant behaviour patterns can show variety according to the subjective factors; comfort needs, lifestyle, gender, age, social life and interactions, values, ideologies [14], however, these factors are quite subjective to assess, and it is quite hard to evaluate them without proficiency in social sciences knowledge as psychology and sociology. All these subjective factors have a relation with each other.

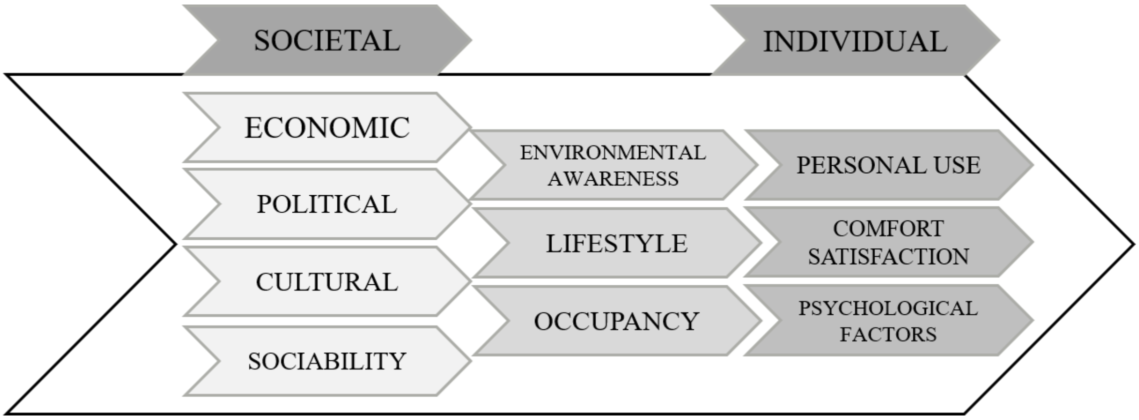


Figure 2:Subjective Internal Factors on User Behavior (Author)

The study of Hong et. al. [15] presents two main behavioural patterns as; adaptive behaviours; where the occupants engage with the actions to control the indoor environment according to their needs and wills they need to adapt themselves to the environment; by changing their locations in the space and changing clothing. The second one is non-adaptive behaviours such as the presence of occupant and the operation of plug-ins and electrical equipment; also reporting dissatisfaction [15]. This study performs to evaluate the impact of adaptive behaviours first part, where the changes are to adapt the environment to occupant needs.

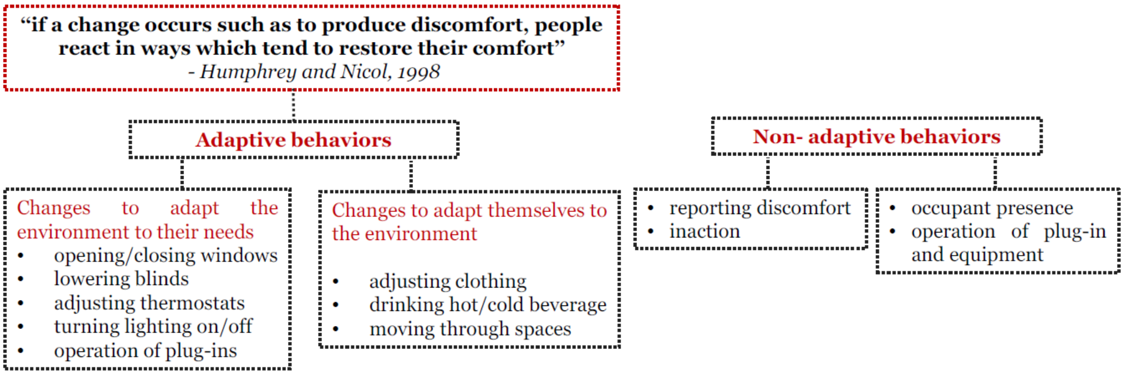


Figure 3 Adaptive and non-adaptive behaviour influencing the energy consumption [15]

2.1.1 Economical

Economic factors are considered in two-scale, one is the energy poverty of the country which is related to political factors and where individual users personally cannot have direct influence. The second one is from the individual perspective, no matter how wealthy the country is, there still might be people who cannot afford energy unless the policies are socially democratic [16]. Given that, the scale here is from an individual point of view; the focus will be made to the personalized use. Economic factors create differentiation between the people in the community where they are liable to the same energy company, same unit energy price but cannot afford the monthly bills or is generous about energy use. Since energy is not a free good, provided by the governments; individuals need to set their boundaries. While some people can choose to continue with the optimum setpoints, others can choose their comfort setpoints.

2.1.2 Political

Even though policies are defined by the governmental institutions; every act of a citizen is affected by political decision such as the right to energy, energy poverty; ranging from household energy conservation, adoption of efficient and renewable technologies, sustaining public support, climate mitigation policies [17].

2.1.3 Cultural

The lifestyle of the buildings shows similarities in local places no matter how globalized the world is. Lifestyle, people's behaviour, and their dressings show similarities in a group of people living close by; where even the comfort temperatures can show similarities. [18]; To further exemplify the cultural effects; having a lunch break at home is quite uncommon in the mega-city Istanbul, where the transport between home and work is 1 hour approximate; that’s why the common thing is the companies providing lunch meal which creates a difference in equipment and hot water use at home.

2.1.4 Sociability

Social factors refer to the social life of the user, the family their occupation and their social & recreational activities, their time spent at home creates a huge difference. Their sociality, having guests over, spending time with friends at home are all personal preferences and will create a difference in energy consumption. The sociability of the occupants also affects the occupancy schedules; if the place is a shared living, a family home, or a single user is living beneath all the economy-related issues.

2.1.5 Occupancy

Occupancy is the number of occupants at home and the use schedules of heating, cooling devices, appliances, lighting. On the other hand, the occupancy density is the number of people per unit area [19]. Occupancy density prevents the inequality provided by the household synthesis as the number of rooms and only creates a comparison between unit floor area occupancy.

2.1.6 Comfort Satisfaction

Even though there are average standards from the regulations regarding this, each person has different comfort needs; thermal comfort, indoor air quality comfort [15]. If there is a possibility to arrange manually, every user living in the same apartment might arrange their thermostats at different setpoints to require their comfort satisfaction.

2.1.7 Personal Preferences

This refers to the private needs, especially about the use of appliances and lighting at home. Use of the kitchen appliances, hobbies, free-time activities, the time that occupant is awake; are factors that have always been neglected at the deterministic approach while building energy simulations tools are used. Variables as gender, age, study level play a crucial role in the definition of personal needs [20].

2.1.8 Psychological Factors

The relation between consumption and psychology is inevitable and a topic that is examined by behavioural economics [21]. Even though many social and psychological factors influence are not easy to quantify as norms, energy-saving attitudes, perceived behavioural control, environmental concerns, trusts and motivations, integrating these considerations allocates researchers to grasp the dynamics of the energy problem [15]. Including the socio-psychological factors will increase the consistency and accuracy; and researchers, engineers, architects & policymakers to embrace the effectiveness of promoting energy efficiency strategies and their development [15].

2.1.9 Environmental Awareness

While climate change has peaked and individuals became aware of the depletion of sources, extreme use of household water and energy; awareness level of people individuals affected their way of consuming the household goods [22]. Without environmental protection, many ecological destructions are possible to happen in the future due to the irrational use of sources as energy and water; pro-ecological individual behaviours are positively affecting this phenomenon [23].

2.1.10 Lifestyle

At the beginning of 90`s the lifestyle concept from societal sciences encounters energy consumption as *“a sense of differences among individuals.”* [24]. Lifestyle is a combination of different factors explained above social, psychological, personal, economic and cultural. Mainly our consumption habits are influenced by our idols and way of living.

The combination of these internal factors leads people to use their time at home in a variety of ways. This time use at home differs from country to country which strengthens the effect of economic, cultural, political external factors metamorphosing into internal factors. The statistical leg of the European Union, Eurostat has significant survey analysis and data proving these points. The Harmonized European Time Use Surveys (HETUS) [25] had been running a survey in 18 different countries between 2008 and 2015 for “time use” spent at home [20]. As it can be read from this figure, individuals from different countries spend their time in different ways which can be explained the effect of the external economic, political and cultural factors metamorphosing into internal factors.

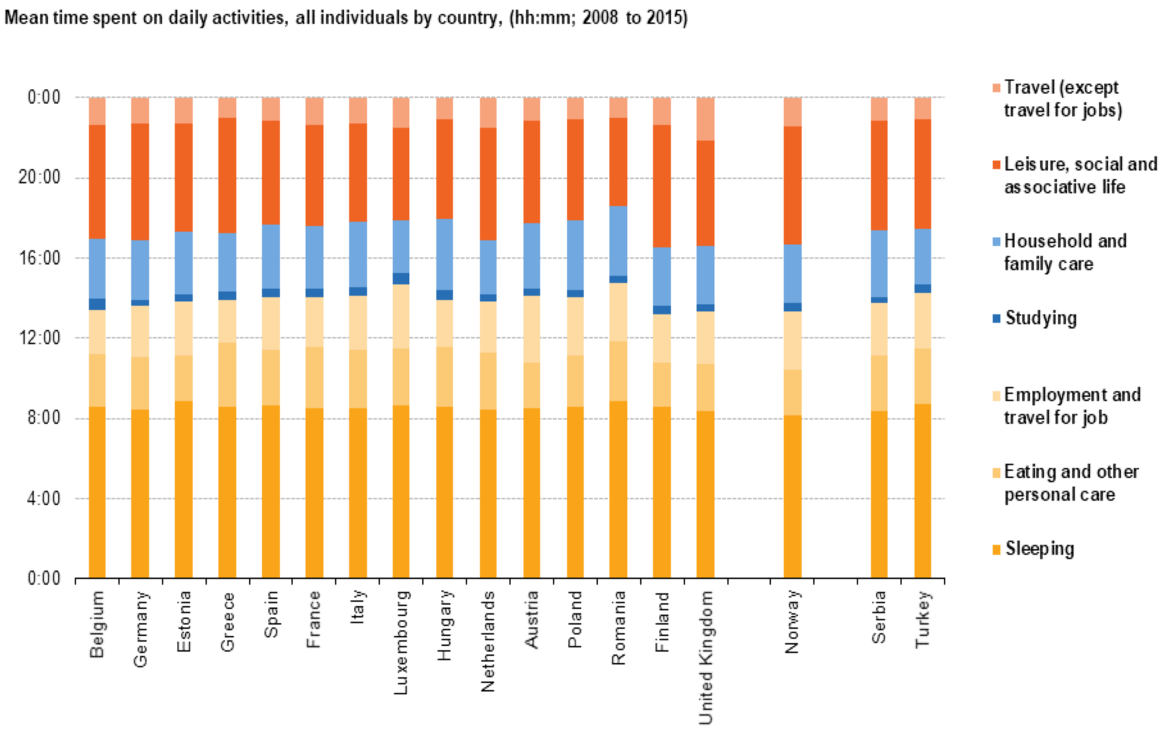


Figure 4 Individual Mean Time Use [25]

2.2 Building Energy Simulation Tools

Building Energy Simulation tools models aim to predict the energy demand in buildings. The accuracy of the modelling can change according to the data input and real-life practices differ from the simulation. Building energy simulation tools not only deal with the energy demand but also predict the energy consumption, while at the same time they enable the design of beneficial HVAC system [26]. BES tools decrease the burden of any complex calculation on spreadsheet programs [27]. Energy simulation tools can be examined in two groups: Graphical User Interface (GUI) and non-graphical [27].

There is a variety of building energy performance tools at the market currently; the most well-used ones will be evaluated to choose the most appropriate one for this study to evaluate the direct impact of users in heating, cooling, lighting, equipment, and domestic hot water demand. These tools are generally not in the open market and companies can develop theirs [27]. Some representative BES tools are provided below:

DOE-2

It is a widely used freeware for building energy analysis, making predictions for energy use and cost of different kind of buildings [28]. It uses data inputs such as building layout, construction materials, usage, lighting, HVAC systems and appliances to execute an hourly simulation of energy use and cost analysis [28]. Its extension eQuest facilitate every type of users work with its practical interface.

EnergyPlus

It is a whole building energy simulation program for professionals from different backgrounds as architects, researchers, engineers which assesses the energy variables of the building as well as other loads as water use [29]. It can provide and process hourly data, simulate HVAC and lighting strategies and size them, provide heat balance-based solutions and create a standard summary and detailed reports about energy consumption, carbon emission and indoor comfort [30]- [29]. It is a product of DOE which stands for U.S. Department of Energy. Nevertheless, EnergyPlus is a stand-alone energy simulation program [31].

DesignBuilder

DesignBuilder Software is a sub-program of EnergyPlus with a graphical user interface, simulating to make a quick environmental performance assessment of new and existing buildings [29]. It enables performance analysis as energy and comfort, HVAC, daylight, cost, design optimisation, BREEAM/LEED credits, reports for certification standards [29]. It is a subprogram under EnergyPlus which is a whole building energy simulation programme for multiple uses as heating, cooling, ventilation, lighting and plug and process loads, and water use in buildings [30]. It also reports solar gains in the surfaces, surface temperatures and radiant exchanges while assessing passive performance, thermal mass and temperature distribution [32]. Additionally, assesses building operational and whole life-cycle costs through industry-standard calculation methodologies [32]. It has a ResultsViewer interface to create data reports that will be generated by EnergyPlus.

DesignBuilder has a graphical BIM interface, that helps engineers; mechanical engineers, civil engineers, and architects to be familiar with the program easily. Weather and location data is uploaded to the program directly detailly as heating-cooling degree days. Its graphical interface allows everybody to easily use the program, unlike EnergyPlus which necessities expertise [32].

OpenStudio

It is another software tool supported by EnergyPlus for whole-building energy modelling use with good quality work for daylight analysis [33]. It is an open-source product that can be used in public and industrial use. It is a cross-platform collection of software tools for Windows, Mac and, Linux [33] and can be used at the design phase of a building for everyone involved as, building owner, architect, engineer, researchers, and software developers [33] and it is primarily built as Application Program Interface (API) for EnergyPlus but it does have a Graphical User Interface (GUI) and used as a plug-in for SketchUp, ResultsViewer, Parametric Analysis tool, OpenStudio Application [33]. It processes data of envelope characteristics, loads, schedules, and HVAC [33].

Green Building Studio

It is a cloud-based software of Autodesk, to run BES optimizing energy efficient and achieve carbon neutrality. It is a practical tool to design high-performance buildings and can be used altogether with Autodesk Revit for a whole building simulation which enhances the accessibility of the software by engineers and architects as Revit is a widely used tool. It uses the validated simulation engine DOE-2 to evaluate water use, energy use and carbon emission analysis. Whole building energy analysis provides reasonable energy cost predictions for the final decisions and feasibility studies [34].

Sefaira Trimble

It is a product of SketchUp to magnify building performance which can run annual simulations in a comparably short period. It has fast and easy use by modelling the geometry at SketchUp, running the analysis in few minutes and gives access to work as a team as well as across firms through a shared project on its cloud-based platform. It is mainly targeting architects to orient their designs to reveal a more sustainable building design, comparing the massing, layouts and envelope options, natural ventilation, and natural lighting strategies [35].

CYPETHERM Suite

It is a part of a group of programs called CYPE that is to carry out thermal and energy analysis of buildings altogether with their lighting-acoustic design and fire regulations implementation [36]. It has 13 subgroup programs including the programs run with BIM workflow via the IFC4 standard and can work with 3D models [37].

Table 1 below is the synthesis table of the representative Building Energy Simulation tools; in the market, there is more software, however, for this study, the mentioned software is chosen to evaluate. The evaluation is made according to their main function, interface (API or GUI), data input, audience-users and data output as reports, usage, cost.

Table 1: Comparison Table of BES Tools (Author)

	DOE2	Energy Plus	Design Builder	Open Studio	Green Building Studio	IDA ICE	Sefaira	Cypetherm Suite
Company	DOE	DOE	EnergyPlus	EnergyPlus	Autodesk	EQUA	Trimble Inc. (SketchUp)	CYPE
Graphics	With Extension	With Extension	Integrated	Integrated	Integrated	With Extension	With extension	Extension
Main Function		Whole building energy simulations Water use HVAC design Lighting design Energy use & cost analysis Carbon emission Indoor air quality Sustainability reports [30]- [29]	Energy consumption in buildings HVAC design Energy use Energy cost analysis Occupant Comfort analysis Design Water use and loads optimization LEED/BREEAM Reports LCA cost analysis	Building Energy simulation modelling Daylight Analysis Loads HVAC design [33]	Whole building energy simulation analysis water use, energy use, carbon emission analysis energy cost analysis [34]	Indoor climate Energy consumption analysis Occupant comfort analysis	Building energy performance analysis	Thermal and energy analysis of buildings Lighting design Sound and fire extinguishing installations [36]
Audience	Building Energy experts, Engineers, Researchers, Industry experts, HVAC designers [28]	Energy Engineers, Researchers, Industry experts, HVAC Designers Students [30]-[29]	Architects, Engineers, Researchers, Industry experts, Teaching Professional, Students [38]	Architects, Engineers, Researchers, Building Owners, Software Developers (Open source) [33]	Architects, Engineers, Sustainability Consultants, Energy Consultants [34]	HVAC designers Engineers Simulation experts, Researchers, Students [38]	Architects, engineers, sustainability consultants [38]	HVAC designers, Engineers, Energy experts
Input	Building layout Construction materials Usage Lighting	Building layout Construction materials Usage Lighting	Weather Data Location Building layout Construction materials	Building model, Building envelope characteristics, Loads, Schedules,	Weather Data Revit Integration [34]	2D and 3D CAD files Climate files [38]	Architecture Plugins geometry (3D Model from Sketchup or Revit)	2D, 3D CAD files Building layout, Floor plans

	HVAC systems Appliances [28]	HVAC systems Appliances [30]- [29]	Usage Lighting HVAC systems Appliances Occupancy Activity Schedules	HVAC system [33]			Building location and type Weather data [38]	Construction Materials Thermal bridges (regulations) HVAC systems Internal loads and schedules [39] EnergyPlus climate data file format (EPW)
Output	An hourly simulation of energy use and cost analysis [28]	An hourly simulation of energy use and cost analysis HVAC sizing Lighting strategies, solutions heat balance-based solutions [30]- [29]	An hourly simulation of energy use and cost analysis HVAC sizing Lighting strategies, solutions heat balance-based solutions Daylight analysis, Design optimisation, BREEAM/LEED credits, Reports for certification standards	Energy consumption analysis Daylight Analysis [33]	Building energy performance simulations optimizing energy efficient and carbon neutrality [34]	Localized reports 3D visualizations Geometry, Solar shadings Ventilation and airflow visualization Window energy balance Wind-driven flows LEED forms	Building energy and water use Carbon emissions Utility costs Renewable Energy potential Healing and cooling capacity Daylight visualizations Annual and point in time daylight analysis Daylight [38]	Energy demand report Energy consumption report Condensation Description of materials and construction elements Linear thermal bridges Internal comfort

2.3 Gap Between Energy Simulation and Operation Use

To increase the accuracy of data-driven building energy simulation tools and decrease the gap between simulation and real-life results; necessary data should be entered in a more comprehensive way [15]. Lawrence Berkeley National laboratory`s report [15] presents 10 questions around important factors in occupant behaviour research as a guideline for researchers, designers, and policymakers [15]. This study carries importance by having a sociologist on the research team and evaluating the questions in an interdisciplinary way.

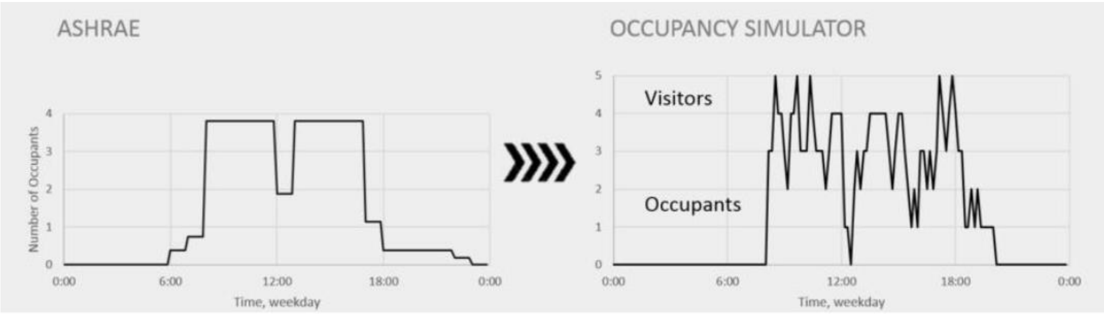


Figure 5 Comparison between the standard ASHRAE Occupancy profile and Stochastic occupancy schedules [15]

2.4 Review of Related Cases

2.4.1 Bilbao, IDOM Case

This case was the point of attraction for the theme of this thesis: understanding the state of humanity in future cities as everything becomes "smart", from home automation to urban mobility. However, there was one specific issue that reminded the importance of how the utilities are used, or how office/home spaces affect energy consumption. The example brought up belongs to the IDOM building in Bilbao; it is an open office space consisting of different thermostats, each controlling a terminal unit. According to the interview notes with the engineer Mr Jon Zubiaurre Sasia; the setpoint temperature could be adjusted through the thermostats T1, T2, T3, T4 where each user has their thermal sensation and these thermal sensations are depending on person’s metabolism, activity, clothing, time of the day, sex etc. [40]. Each user was able to change the temperature by +/- 3ºC above the setpoint temperature. Although there is an optimum comfort level, the comfort temperature changes depending on the individual; this resulted in neighboring office workers setting different temperatures e.g., 20ºC and 26ºC [40]. There were incidents where two employees working next to each other switched two terminal units to heating and cooling mode [40]. This eventually, led to an uncomfortable environment where both users weren`t drastically satisfied and caused a waste of energy [40]. Other findings of the engineering team were that the U-value of the walls and ceiling, which caused a surface temperature of 17 ºC which was below the comfort temperature, ended up with the users setting the thermostat temperature to 27 ºC [40]. Even though the choice of the users was arbitrary, the use of the thermostats was dependent on the specific location they were in; while it was next to the windows there was sun radiation in the summer and irradiative losses in the winter [40]. Since this real-life example shows the impact of user behavior in the context of energy saving; this study will take it further by comparing different scenarios. The final point made by Mr Jon Zubiaurre Sasia was that energy consumption depends on occupant`s behavior where manual thermostat control unit is present.

2.4.2 Copenhagen Case: Effect of thermostat and window opening occupant behavior models on energy use in homes [11]:

The study focuses on occupant behavior that affects the building performance by controlling the devices such as windows, radiators, valves, shading elements and changing the indoor conditions [11]. Furthermore, the study focuses on quantifying the effect of thermostat and window opening through the probabilistic modelling approach was used in this study. According to this methodology, real data were collected from environmental and behavioral measurements in the field, data analysis of the influencing behavioral parameters were performed, probabilistic models were implemented, simulations were run, and outputs were distributed [11]. IDA ICE tool was used for the simulation in this study, and it is important for the case study for having a similar core idea behind; supporting probabilistic approach to show how simulations are not beneficial for real-life use and have a weak representation of the possibilities in use.

2.4.3 Istanbul, Dormitory Case: The Impact of User Behavior on Energy Consumption - A Case Study of Kilyos Saritepe Campus Dormitory through Hong and Lin grouping methodology [27]:

This is a dormitory where undergraduate students of the university live for the two academic periods of fall and spring. In this case study, electricity consumption is investigated by grouping students into different clusters according to their occupancy and energy consumption tendencies. The salient reason that led the study into research was the neglect of occupants' energy consumption behavior in the prediction of energy consumption studied [27]. A previous study conducted at Lawrence Berkeley National Laboratory [41] had found that the best way to cluster the students into three theoretical groups according to their daily lifestyle. 5 to 30 percent of energy savings can be gained through occupant behavioral patterns [27]- [41]. The classification made by Hong and Lin consists of 3 groups: i) *austerity residents* which are active at energy conservation ii) *standard occupants* who make the average level of consumption iii) *wasteful occupants* who are not concerned at all [27]- [41]. Hong and Lin`s methodology [41] is based on the literature review as well and the post-occupancy surveys by the occupants. Later, they proceeded with the simulation of the building by inputting the schedule data of variables to perform analyses of this office building according to three hypothetical group at three different climates [27], [41]. As in Hong and Lin`s study [41], Kazar and Comu [27] had followed a similar approach. In this study, the first step was surveying the students to group them, later the factor analysis was made to decrease the effect of unconsidered variables, this optimum cluster number was found by iteration methodology and students were distributed. Later the study was carried out at DesignBuilder and the assumption was if the dormitory was occupied from one cluster at the same time and the comparison is made according to the results of these 3 clusters occupying the building at once. This comparison is made with DesignBuilder default settings too also [27]. This study carries a similar methodology that will be carried out in the case study by grouping the users and the simulation software.

2.4.4 Iran, Residential Case: A study of the impact of occupant behaviors on the energy performance of building envelopes using occupants' data [42]:

This study [42] aims to investigate the influence of occupants` lifestyle patterns regarding energy consumption, for different building envelopes and climate zones. An existing multifamily apartment was selected as a case study and the energy demand of the building, before and after retrofitting was simulated using Energy Plus. The simulations were conducted in three different climate zones in Iran, as the country has different climate zones in almost every zone due to its large area. This study is important and has similarities with the current study by pointing out that how important personal preferences and occupants` lifestyle are to energy consumption. The results are expected to show the interaction between the building envelope and occupant behavior [42]. How it is carrying the study out by internal load and thermal performance. The study shows how internal load and thermal performance affect energy consumption. It is also important to note how different the results are when evaluating stochastic and deterministic building simulation models.

While the relation between occupant behavior and energy consumption at buildings are being examined, some groups of researchers [42] were focusing on the grouping of the occupants according to the lifestyle; some researchers were assessing their relationship between thermal envelope, constructions materials, control elements of HVAC and climate.

Occupant behavior effects energy use in buildings; there are many more variables effecting the energy consumption in buildings such as climate, building orientation and locations, construction materials, thermal characteristics of these materials, the function of the building, HVAC design, thermostats, setpoint temperatures, windows opening schedule etc. Therefore, the analysis should be done as a whole to have an accurate level of evaluation results to understand the impact of occupant behavior in all these which will highlight the originality of the work.

Table 2 Assessment of Literature Review Studies (Author)

Assessment / City	**Bilbao**	**Copenhagen**	**Istanbul**	**Iran**
Building Envelope		X		X
Thermostat	X	X		
Window opening		X		
Indoor air quality	X			
Internal Load				X
Thermal Performance				X
Heating	X		X	
Cooling	X		X	
Electricity			X	
Different Climates		X		X
Energy Cost		X		
CO2/Climate Change effect		X		
Period	-	Annual	Annual/Monthly	Annual
User Grouping	-	-	X	-
Modelling Approach	-	Deterministic - Probabilistic		Stochastic - Deterministic
BES Tool	Multiple	IDA ICE	Green Building Studio	-

3 Methodology

Three buildings from three different regions with three different thermal characteristics of buildings are evaluated by 63 combinations, iterating two main occupant behaviors; economic and wasteful, constituted the variable amalgamations of occupancy, heating, cooling, DHW, ventilation, lighting, and appliances. There are two sets of scenario simulations; first set is SC_0, SC_1_1, SC_1_2, SC_2_1, SC_2_1, SC_3_1, SC_3_2 scenarios which is 27 simulations in total. The second set of simulations are the crosswise simulations of the original scenarios of 36 simulations.
The simulation is performed using DesignBuilder and the comparison results are analyzed to determine the effect of occupant behavior on building energy demand. The simulation examines the energy demand, which is the immediate rate of energy consumption.

3.1 Why Design-Builder?

EnergyPlus is well dominated in the industry, providing effective energy use and cost reports. As sub-software of EnergyPlus; DesignBuilder [29] is the most commonly chosen product by researchers and professionals due to having an easy interface that provides hourly simulated data in building energy simulation. Since this research aims single model building simulation, it is more convenient to pursue with DesignBuilder. Both the input and output processes provide an easy user experience for data entrance, processing and reporting. Although it is easy to use, it is not opensource software.

3.2 Data Inputs

The following data inputs represent the necessary data that must be entered into the DesignBuilder software to perform the required simulations.

3.2.1 Location and Climate

Location of the building is significant for climatic data; it changes every input of weather database, these parameters are dry bulb temperature (°C); wet bulb temperature (°C);

atmospheric pressure (hope); global solar irradiation (W·h/m²); diffuse solar irradiation (W·h/m²); cloud cover (oktas); wind speed (knots); wind direction (degrees clockwise from north); and Present Weather Code [43]. These inputs are essential for building energy, comfort. Daylighting simulations to provide key environmental conditions.

3.2.2 Settlement and Building

Apart from climatic locations, settlement parameters should also be considered; orientation of the building, building type, building geometry, compactness, height, number of floors, shadow analysis, its surrounding, percentage of openings are the important parameters that effect the building energy consumption. According to Du et al. [44]; the effects of the architectural layouts on energy use are higher than on occupant comfort. Architectural design is one of the most important factors effecting building energy performance (BEP) with the design variables such as the function of the buildings, width, lengths, height, form, partitions, openings and building envelope [44]. In the review study of Du et. al. [44]; up to 14% and 57% heating and cooling demands were decreased by changing the space layouts. For further exploration, the building type gives the general idea about the use, as if it is a residential, commercial, use schedule of the building daily and annually. Orientation of the building gives importance to the energy demand due to the solar gains and losses. The geometry of the building, height, number of floors, percentage of openings, and compactness influences heat loss, heat gains, infiltration, and solar gains which influence the heating and cooling load [26]. Its surrounding and the effect of other buildings extracts the shadow analysis to calculate the thermal and solar gains-losses too. Thus, there will be different building typologies with different building geometries to increase the variety and detect the most dominant factors.

3.2.3 Construction Materials

In addition to the general features of the building, construction materials are highly important due to their thermal characteristics. Envelope materials and openings are affecting the thermal loads the most; they are also affecting the ventilation, air leakage, ventilation, conductivity through their density, thermal mass, and U-value [26].

3.2.4 Energy Demand Settings

Heating and cooling temperature setpoints, the approximate daily use of hot water will create a reference for the calculation of heating and cooling energy consumption and domestic hot water use. These setpoints have a baseline but they can be changed by the user from manual thermostats and unquestionably heating degree days & cooling degree days affects the final consumption output.

3.2.5 Occupancy and Use

As mentioned earlier, the building type and the function has a major impact on energy use, if it is a residential building the schedule of occupancy and heating, cooling, electrical appliances changes the indoor comfort requirements greatly, resulting in differences at both input and output levels. The data inputs to the DesignBuilder as the number of people, schedule and setpoints, activity, metabolism, the density of people per meter, lighting conditions (W/m² and type of lamps), equipment use diverges.

Variables

- Occupancy & Occupancy schedule: This data input of DB affects the use of heating, cooling, and domestic hot water. An occupancy unit is a person per square meter and the schedule is the time that the apartment is occupied.
- Heating Setpoint & Period, Schedule: The heating period and schedule stand for the annually period (wintertime) daily time that the heating system is being used. The heating setpoint temperature is the room`s targeted temperature for the winter period which can be arranged through the control device.
- Cooling Setpoint & Period, Schedule: The cooling period and schedule stand for the annually period (summertime) daily time that the cooling system is being used. The cooling setpoint temperature is the room`s targeted temperature for the summer period which may be arranged through the control device.
- DHW: It is the average amount of hot water in liters that will be used by one person where the calculation depends on the occupancy.
- Ventilation: The data input ventilation is air change per hour (ACH). It is related to the window opening schedule.
- Lighting, Illuminance (lux), Installed power (W/m²), Schedule: Lighting data will be entered through the installed power, illuminance, and the schedule of lighting use which will depend on the day/night.
- Appliances, Installed Power (W/m²) & Schedule: The use of appliances depend on the installed power and occupancy schedule mostly.

3.3 Quantification

3.3.1 Heating and Cooling

It will be evaluated through DesignBuilder EnergyPlus program along with an assessment of different heating schedules and periods while the simulation will run on an annual basis.

On the other hand, cooling depends on the climate, natural ventilation, and usage schedules [45] since the assessment is done at residential buildings and it is not common to have centralized cooling systems at residential buildings, and so the selected buildings don`t have a centralized cooling system.

Natural Ventilation: ACH has standards by ASHRAE, nevertheless the occupants may prefer non-standardized ventilation rates. HVAC systems are not a data input neither a variable. The results will only be evaluated from kWh/m^2 unit.

3.3.2 DHW, Domestic Hot Water

Hourly use in the kitchen, bathroom, WCs and shower occurrence, winter-summer situation. Domestic hot water: According to The Spanish Technical Building Code (Royal Decree 314/2006 of 17 March 2006) [46]; daily use of hot water is 50 lt per person in Spain, this information will be taken as reference. On the other hand, for Istanbul, the daily use of water consumption is a lot higher with 113,6 lt [47].

3.3.3 Equipment & Lighting

Hourly and weekly use of equipment, home office or work situation, use of domestic appliances by the occupant in residential buildings affect the energy use directly. This part quantifies the energy demand from appliances and lighting

4 Case Studies

The case study has a total of 63 simulations of different schedules at three different buildings and their crossings between each other. Since the solar gains are different in different locations, the results will be varied for both regions, that`s why while comparing different locations with the same occupancy properties; the base/non-scenario version of the study should also be considered.

Compared to Europeans, comfort temperature for individuals differs in Turkey, that leads heating and cooling set-point temperatures to be higher to reach their indoor comfort temperature [48]. This can be explained by the low thermal situation of the buildings or the preferences of individuals.
Additionally, different building typologies are evaluated to show that our preferences for where we live are also a user behavior decision; a multistorey building, an attached apartment building, a single-family building will have different results about energy demand in buildings. Different building typologies will also have different heating and cooling system to support the needs.
Different building typologies will not only have different energy demand results; but also provide clues of the occupants` lifestyles.

4.1 Limitations

The selected buildings in this study are from different sources. The first is a research study from the Basque country, to evaluate the effects of the Basque country. The second one is from TABULA web tool and the third one is architectural design work.

Insufficient data from the countries` energy-saving technical code/implementation documents directed the study to make assumptions to use the same technical code CTE [49] from Spain as a base scenario. A further study from the governmental legs determining the optimal periods, schedules for occupancy, heating and cooling and heating-cooling setpoints would be particularly valuable.

CTE regulations carry out weekdays and weekends with the same amount of use thus, the results have only a reflective meaning. This insufficient data gathering to determine more accurate occupant behavior is a phenomenon that currently researchers are working on; by collecting the data of human interaction with the building through physical sensors and non-physical sensing methodologies [15].

Additionally, the subjectivity of behaviors makes it difficult to quantify human behavior and many assumptions and generalizations are done in the scenario scheduling.

4.2 Assumptions

- Occupancy: is 0.03 for the base studies, which means 3 people per 100m² for all base scenarios.
- Occupancy Schedule: Occupants are employed adults between 18-65.
- Spanish Technical Code is the base scenario for all three climate zones to define, schedules and setpoints due to the insufficient data from Belgium and Turkey regulations.
- In this study, the impact of occupant behavior on energy consumption is investigated, therefore indoor air quality or internal comfort is not a target to be achieved, which does not give importance to the time setpoints not met during the hours of use.

4.3 Locations

In the case study three existing buildings one from each from three different regions (Basque Country; San Sebastian, Turkey, Istanbul and Belgium, Brussels) are investigated to understand the effect of the user behavior over energy consumption in buildings in different climates. Both three regions have different understanding and system in the construction industry which reflects on the building materials. Additionally, the consumption habits of the occupants differ in a considerable amount due to the culture and lifestyle. To follow up with an example; eating habits and the number of time citizens spent at their home are different. Istanbul is a large mega city with a high consumer mentality of people which results in people working a lot [50], eating outside, spending a lot of time in traffic, and using their home as a shelter in a normal (pre COVID) time. On the other hand, San Sebastian is comparatively smaller than the other two cities where people have long, 2-3 hour breaks at their workplaces where they can go home to cook and eat. This kind of behavior is very unlikely to be seen in Istanbul, the people from this megacity cannot go home for lunch breaks or generally cook the day before for their lunch breaks due to spending a lot of time at the traffic. During the time, this comparison has many sociological discussions at the background, this study will only evaluate their effect on energy demand.

The comparison of three different regions; one from the Middle East, Istanbul, Turkey, San Sebastian, Spain and Belgium from Europe (Figure 6) explains the consumption habits of the occupants, even though every individual cannot be generalized, these two cultures have different ways of acting about consumption which also encouraged by public policies. On the other hand, Belgium is the heart of the European policies and a pioneer in sustainable construction developments and energy efficiency policies.

Figure 6 Map of Case Study Countries (Author)

4.3.1 Location 1: San Sebastian, Basque Country, Spain

The first location is chosen from Basque Country, as the main base of the research study. Moreover, Basque country has a great effort about achieving energy efficiency in buildings, by retrofitting and renovating the current buildings [51]; and designing the new buildings according to these delicate regulations. Basque Country has a 2050 action plan named “Bultzatu 2050” [52] showing the roadmap for 2050. San Sebastian has an oceanic climate according to the Köppen climate classification (Cfb) with mild winters and warm summers [53].

4.3.2 Location 2: Brussels, Belgium

Brussels is the capital of the European Union, which makes it the first target to implement the new policies. It is politically far ahead of the other locations, San Sebastian, and Istanbul. Belgian National Plan for Nearly Zero Energy Buildings [54] which was published in 2012 supports this idea. Moreover, it has a different and comparably colder climate than the first options. Belgium has a “Marine West Coast Climate” with the subclassification "Cfb" climate according to the Köppen Climate Classification.

Different climatic conditions cause discrepancies between the countries to happen, possibly due to the different climatic conditions. In the diversion of countries building energy uses, space heating acts a major role, thus southern countries are dissociated from the north European countries [55]. On the other hand, European Union has directives to take control of the ongoing situation in European countries and make recommendations or legislations for countries to follow these rules. According to EPBD, Member States are obliged to act on the needed measurements to achieve low cost and low energy solutions [56]. European Union has many roadmaps to reach nearly zero energy buildings by 2020 and forwards, and projects under BUILDUP promotes the countries to reach these goals [13]. The status of nZEB development between the EU Member States in 2016 was divided into three sections; i) Included in an official document; ii) Under development; iii) To be approved. While Belgium has already an official document, Spain`s NZEB status is still under development, and Turkey is not even on the list to be approved [56]. The selection of the climates has been supported with their status of energy efficiency in buildings development.

4.3.3 Location 3: Istanbul, Turkey

The second location is chosen to have a relatively different climate than oceanic, it has a “dry-summer subtropical” climate according to the Köppen Climate Classification with the subtype for this climate is "Csa", Mediterranean Climate [57]. The dominant building typology, energy sources, consumption habits are relatively different from European cities which offers diversity at the analysis of the study. The social and economic developments of Turkey as a developing middle-income country that necessities more energy and energy innovation [58]. Another important point is that 30% of the consumed energy belongs to the building sector at the design and operation phase, in all the sectors [59]. According to Özyurt, it is possible to save 30 to 50 percent of the energy consumed at buildings. This is a huge amount of loss and lately, many more enforcements are implemented countrywide [59]. Both the policies and the environmental awareness level of the community makes Istanbul an interesting place of choice for the comparison of this study.

4.4 Buildings

The building typology will be residential. From each building, the same group of occupants will be implemented through the cultural or personalized way of acting and the rest of the occupants from the buildings will have standardized behavioral patterns to make a more accurate assumption. That means only one flat from apartment buildings will be evaluated.

4.4.1 Building 1: Multi-Storey Residential building from San Sebastian, Basque Country

The first building is a multifamily building from San Sebastian, Basque Country, Spain constructed in 1963; it is suitable for this study because the floors and the apartments are replicable. The building has a 9484 m² total net floor area with a heated surface of 8574 m², consisting of a commercial ground floor and 9 residential floors duplicating each other with 12 apartments on each floor [60]. The current system is a centralized natural gas heating system and natural ventilation is used for cooling. For domestic hot water, the apartments have their private electrical hot water systems, and the building does not have a renewable energy system [60]. This building assumed to have an infiltration rate of 0.1 (r/h). The building`s envelope and thermal characteristics of the non-refurbished version were taken into consideration in this research which doesn`t meet the minimum requirements by the current building regulations [60]. The current state of the building does not cover the minimum thermal requirements arranged by the Spanish Technical Code [49]. After refurbishment, it will have an optimum, thermal state to cover the requirements by CTE. This technical code has an explanatory implementation, unlike many European countries which also follow EPBD guidelines. According to EPEE`s review [61] on countries implementation guidelines Spain has one of the best implementations thanks to CTE.

San Sebastian has chilly summer thanks to the ocean and cool winter where the annual average temperature is 14°C. In summers, the average temperature is below 20°C where the cooling system is possibly unnecessary [60]. This building has been chosen because it is a representative building for the region`s style and has repetitive units that make the quantification efficient.

Different thermal characteristic windows are implemented as the refurbishment phase of this building; low, optimum and high thermal. The windows at low thermal buildings don`t compensate for the CTE regulations. However, the U-values of the optimum and high thermal conditions of the windows corresponds with the regulations.

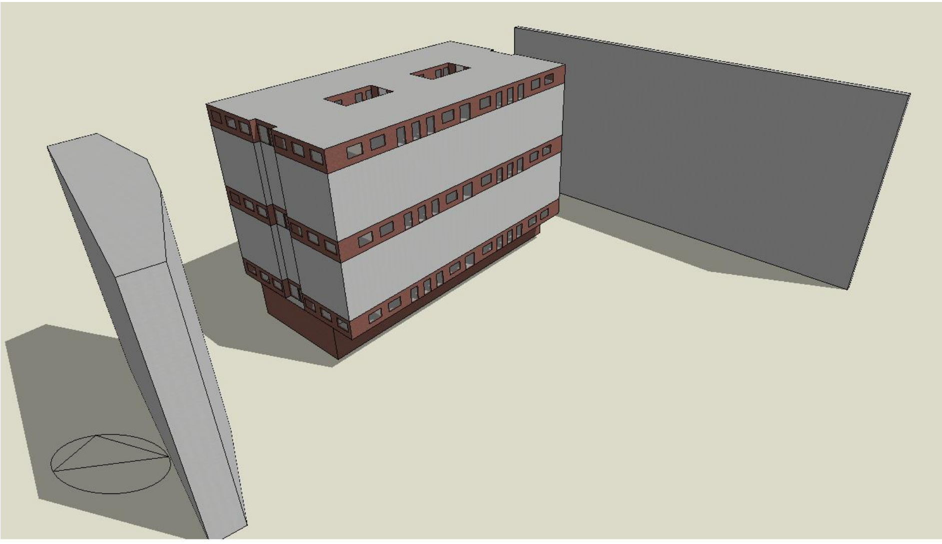


Figure 7 Building_1 [60]

Table 3 Building properties Low Thermal Quality (Author)

Building 1	**Material**	**Thickness(cm)**	**Thermal Conductivity (W/(m-K))**	**U-value (W/(m² -K))**
External wall	Double partition	11	0.375	1.12
	Air gap	5	0.16	
	Double partition	11	0.375	
Internal wall	Gypsum plaster	1	0.55	
	Brick	6	0.595	
	Gypsum plaster	1	0.55	
Floor/Ceiling	Concrete	25	2.5	2.34
Ground Floor	Concrete	25	2.5	1.79
Roof	Ceramic tile	2	1.3	1.100
	Air gap	5	0.16	
	Concrete	20	2.3	
Glazings	Generic Clear	0.6	0.9	5.78
	Aluminum Frame			4.20

Table 4 Building properties Low Thermal Quality (Author)

Glazings	Double glazing	0.6	0.9	2.70
	Aluminum Frame			2.90

Table 4 Building properties Optimum Thermal Quality (Author)

Building 1	**Material**	**Thickness(cm)**	**Thermal Conductivity (W/(m-K))**	**U-value (W/(m² -K))**
Glazings	Low emissity coated glazing	0.6	0.9	1.4
	Wooden Frame			1.2

4.4.2 Building 2: Single-Family House from Brussels

It is a traditional single-family house from Belgium-Brussels, where the exact location is unknown. Its base floor area is 220 m² and was constructed between 1991 and 2005 [62]. It has been chosen to evaluate a different building typology. A single user or a family living in a single-family house shows tips from the lifestyle preferences of users, living in a private house has a high ecological footprint [63].

It has an individual central gas heating system, individual fossil fuel condensing combi boiler without storage and pipelines [62].

This project and its data are from TABULA (Typology Approach for Building Stock Energy Assessment) web tool [64], research of Flemish Institute for technological research (Vito). Its main target is to research the typologies effect on energy assessment.

Figure 8 Building_2 [62]

Table 5 Building_2 Properties Existing State (Author)

Building 2	Material	Thickness(cm)	Thermal Conductivity (W/(m-K))	U-value (W/(m² -K))
External wall	Brick wall	6	0.72 0	0.627 W/(m² K)
	Insulation		0.034	
	Air Cavity			
	Brick wall	6	0.720	
Floor/Ceil-ing	Concrete		1.4	0.70 W/(m² K)
	Insulation		0.034	
Ground Floor	Concrete		1.13	0.70 W/(m² K)
	Insulation		0.034	
Roof	Clay tile	2.5	1	0.565 W/(m² K)
	Insulation	6	0.04	
	Roofing Felt	2	0.19	
Windows	Aluminum, Dual-pane glazing		0.9	3.50 W/(m² K)
Doors				3.50 W/(m² K)

Table 6 Building_2 Properties Optimum state (Author)

Building 2	Material	Thickness(cm)	Thermal Conductivity (W/(m-K))	U-value (W/(m²-K))
External wall	Brick wall	6	0.72 0	0.37 W/(m²K)
	Insulation		0.034	
	Air Cavity			
	Insulation	3		
	Brick wall	6	0.720	
Floor/Ceil-ing	Insulation	6		0.28 W/(m²K)
	Concrete		1.4	
	Insulation		0.034	
Ground Floor	Concrete		1.13	0.70 W/(m²K)
	Insulation		0.034	
Roof	Insulation	8		0.27 W/(m²K)
	Clay tile	2.5	1	
	Insulation	6	0.04	
	Roofing Felt	2	0.19	
Windows	Mount new win-dows, double glazed			2.00 W/(m²K)
Doors				3.50 W/(m²K)

Table 7 Building_2 Properties Advanced Refurbishment (Author)

Building 2	Material	Thick-ness(cm)	Thermal Conductivity (W/(m-K))	U-value (W/(m²-K))
External wall	Brick wall	6	0.72 0	0.22 W/(m²K)
	Insulation		0.034	
	Air Cavity			

Building 2	Material	Thick-ness(cm)	Thermal Conductivity (W/(m-K))	U-value (W/(m²-K))
	Insulation	8		
	Brick wall	6	0.720	
Floor/Ceil-ing	Insulation	6		0.23 W/(m²K)
	Concrete		1.4	
	Insulation		0.034	
Ground Floor	Concrete		1.13	0.70 W/(m²K)
	Insulation		0.034	
Roof	Insulation	18		0.16 W/(m²K)
	Clay tile	2.5	1	
	Insulation	6	0.04	
	Roofing Felt	2	0.19	
Windows	mount new win-dows, double glazed			1.60 W/(m²K)
Doors				3.50 W/(m²K)

4.4.3 Building 3: Attached Apartment Building from Istanbul

It is a steel building, after the demolition of the old one. The sublevels are made from concrete while the rest is steel. It has a 128,37 m² base area [65]. It is a mid-scale, attached building which is very common in central Istanbul where the urban structure is highly dense and the distance between buildings are low. That being decreased the outside wind and cold effects coming from outside, but it also decreases the solar gains because of the shadows. It was constructed in 2013, which makes it a newly constructed building according to the recent regulations. It has a long glass façade to use the sunlight at the maximum. The energy performance regulations [66] for this building is from the official governance of the Turkish Republic. According to TS 825, Istanbul locates at the 2nd climate zone in TS 825 climate classification and the U values of the building envelope parts should be as in Table 8 below [67].

Table 8 Optimal U-values according to TS 825 [67]

TS 825 Climate Zone	Wall (W/(m²-K))	Roof (W/(m²-K))	Floor (W/(m²-K))	Window (W/(m²-K))
2	0.6	0.4	0.45	2.4

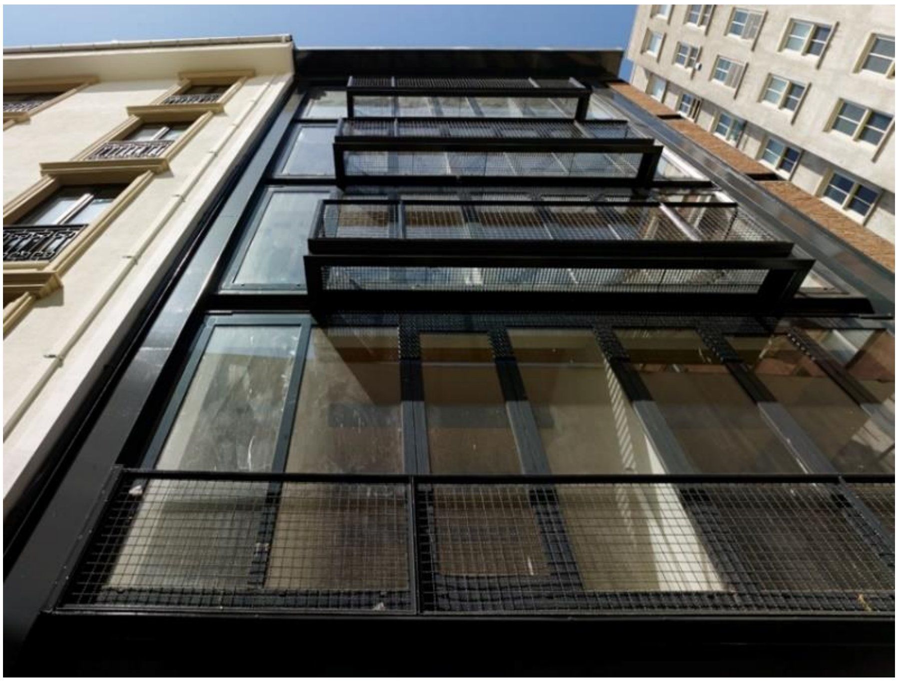


Figure 9 Building_3 [65]

Figure 9 [65], Building 3`s façade shows the materials of the building envelope, a steel structure which also differentiates this building from all others.

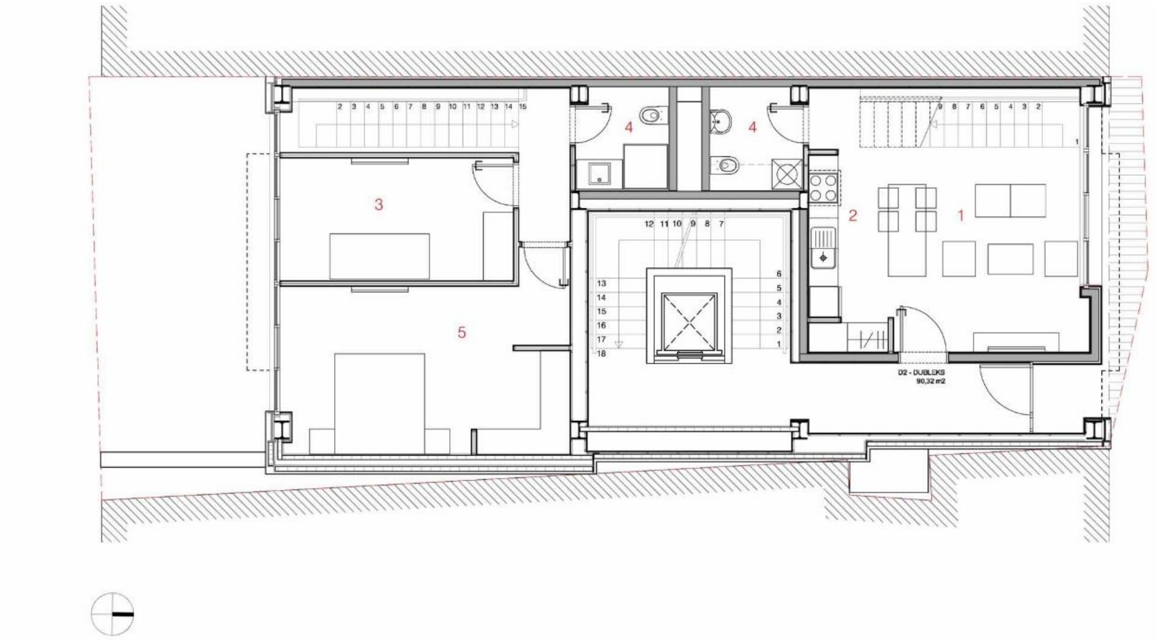


Figure 10 Building 3 Ground Floor Plan [65]

Above, Figure 10 [65] shows the building plan, the building envelopes are open to outside effects from North and South facades.

Table 9 Building_3 Properties Existing (Author)

Building 3	Material	Thick-ness (cm)	Thermal Con-ductivity (W/(m-K))	U-value (W/(m²-K))
External wall	Brick wall	8	0.84	0.54
	Water insulation	0.5		
	Insulation (stone wool)	5	0.04	
	Brick wall	8	0.62	
Ground Floor Exter-nal Walls	Plaster	1	0.16	0.518
	Insulation (stone wool)	5	0.034	
	Reinforced concrete retaining wall		0.51	
	Metal construction		230	
	Gypsum board		0.4	
Floor Ceiling	Plywood	2.4	0.15	0.385
	Metal construction	4*8	45.280	
	Acoustics insulation	8	0.17	
	Plywood	2.1	0.15	
	Gypsum board		0.16	
	Metal construction		45.280	
	Insulation	5	0.034	
	Steel construction (HEA300)		45	
Ground Floor	Stone covering + Mostar	6.5	3.49	0.27
	Reinforced concrete Founda-tion	70	1.13	
	XPS thermal insulation board	5	0.034	
	Water insulation	0.5		
	Lean concrete	10	0.16	
Roof	Zinc	1.5	110	3.16
	Air Gap	3		
	Roofing felt	0.5	0.19	
Glazing	Generic Clear	0.3	0.9	1.96
	Air gap	1.3		
	Generic Clear	0.3	0.9	

The existing state of the building counterposing the Turkish regulations [66], therefore for this building there will be existing and thermally refurbished versions of this building.

Table 10 Building_3 Properties Low (Author)

Glazing	Generic Clear	0.6	0.9	5.88

Table 11 Building_3 Properties High (Author)

Glazing	Triple Loe Clr (e5=.1)	0.3	0.9	1.05

4.5 Scenarios

The combination strategy for scenarios is shown below to provide the diversity of understanding the reasons behind the energy consumption in buildings and eliminate the user behavior from all of them. There are 63 different scenarios for the combinations below in a total of two set. Each color group-main headline intersects with the other. The main combination headlines are Building Typologies, Climate, Thermal condition, and User Behavior. Through the varied combinations of these headlines, the effect of user behavior will be examined.

The standard schedules aka Schedule_0, for Basque Country is from the "Spanish Technical Building Code" Energy Saving document [49]. In Europe, energy efficiency in buildings is protected by European Performance in Buildings Directive (EPBD) which was published in 2010. Thus, for Belgium these directive regulations will be taken as a base; the descriptive Technical document, CTE distinguishes Spain. Later, BEP-TR in Turkey was introduced in 2008, revised in the following years 2010 and 2011 to set the procedures, minimum energy performance requirements. Turkey as a country in the process of membership of the EU, the regulations on energy performance at buildings was inspired by EPBD [68]. "Binalarda Enerji Performansi Yonetmeligi [BEPY, Energy Performance Regulations at Buildings]", also have a software tool named BEP-TR [69] to encounter the energy performance necessities which is obligatory to have for new buildings. The energy efficiency is also protected by the general law "Enerji Verimliligi Kanunu [Energy Efficiency Laws]" [70]. The calculation of the building energy performance rules is defined in the official government regulation "Bina Enerji Performansi Hesaplama Yontemi [Building Energy Performance Calculation Methodologies]" which for the further case study scenarios this document will be taken as the base [71].

4.5.1 Scenario Stories

Economic: The occupants are careful about energy and water use, they work outside and share an apartment so occupancy is higher. These scenarios also do not have a cooling demand.

Wasteful: These occupants are lavish about energy and water use, spend more time inside so that equipment, lighting, heating and cooling use is higher. Occupancy is lower due to the small share of living areas.

Figure 11 below shows the crossing of main topics. Each property from the main headline will cross with a different one, two properties of the main headline won`t cross with each other; for example, a wasteful scenario will never cross with economic scenario but other properties of main headlines, i.e., wasteful as user behavior, optimum for thermal condition and Brussels single-family house will create a scenario.

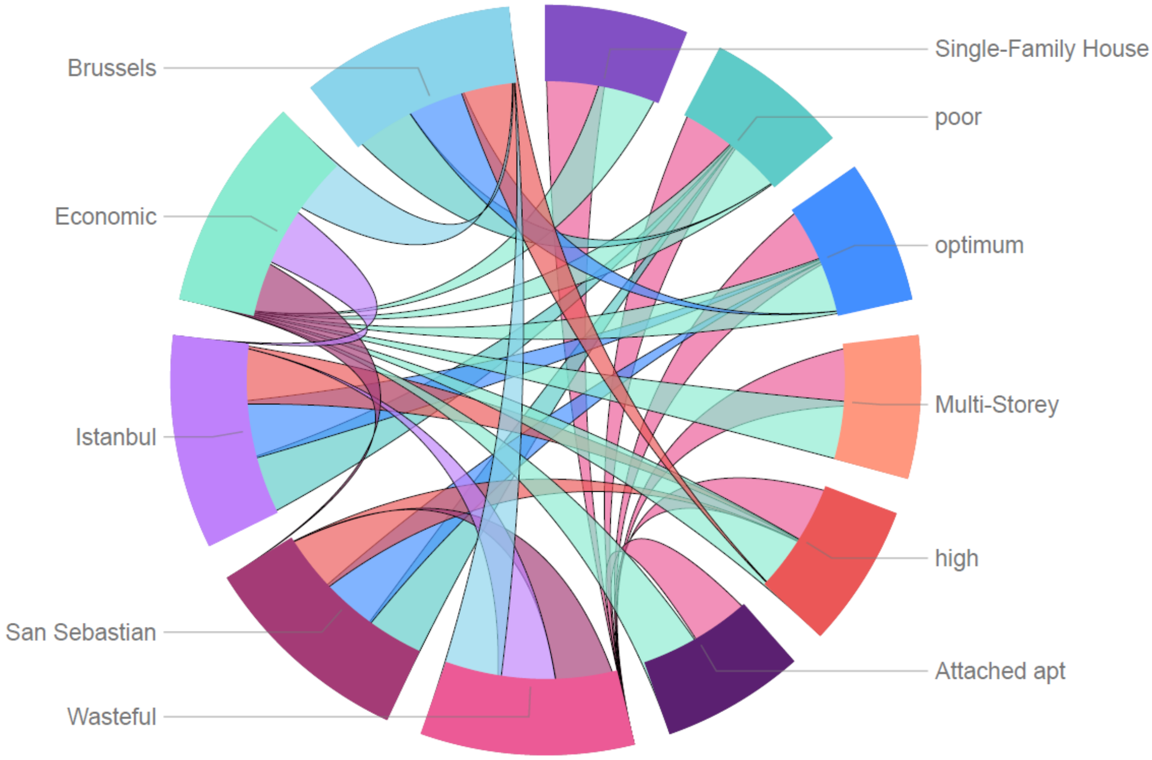


Figure 11: Interaction Map of the subtopics (Author)

The crossing of each specific topic is represented in Figure 11, each head topic User Behavior, Climate, Building Typology and Thermal condition`s subtopics will make a crossing with each other. Below, in Figure 13 each shape and color represent a different subtopic. The results will be compared to evaluate the effects of each subtopic. The combination matrix is implemented for three locations/climates, San Sebastian, Brussels, and Istanbul following the guidelines in Figure 12. In total these eighteen simulations have fifty-four simulations by multiplying three plus nine base simulations make 63 different scenarios.

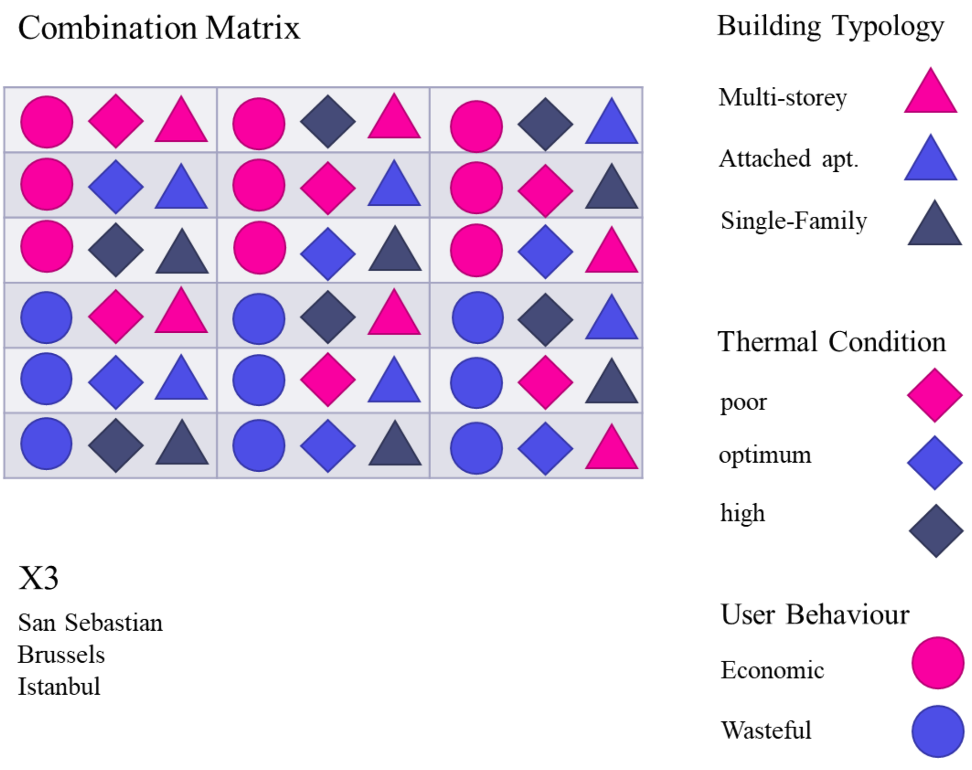


Figure 12: Combination Matrix (Author)

4.5.2 Scenario Tables

Table 12, Table 13 and Table 14 lists the schedules, periods and setpoints of each variable to create scenarios. Each table represents a location and building, the scenarios are run at DesignBuilder as a two-set, first Scenarios below at Table 8,9 and 10 of each Climate and Building typology and then the second set where crossing of each table.

Table 12 San Sebastian Base Scenario from CTE, `standard users`, Economic and Wasteful Scenarios (Author).

Schedules	**San Sebastian**	**Sc 0_0 (CTE [49])**	**Sc 1_1 (Economic)**	**Sc 1_2 (Wasteful)**
Parameter	**Unit**	**Value**		
Occupancy	People/m² (living area)	0.03	0.03	0.01
	Period	Weekdays and Weekends	Weekdays and Weekends	Weekdays and Weekends
	Schedule	Until 07.00 (100%)	Until 07.30 (100%)	Until 18.00 (100%)
		Until 15.00 (25%)	Until 19.00 (0%)	Until 21.00 (0%)
		Until 23.00 (50%)	Until 24.00 (100%)	Until 24.00 (100%)
		Until 24.00 (100%)		
	Period	All other days	All other days	All other days
	Schedule	Until 24.00 (100%)	Until 24.00 (75%)	Until 24.00 (100%)

Schedules	San Sebastian	Sc 0_0 (CTE [49])	Sc 1_1 (Economic)	Sc 1_2 (Wasteful)
Parameter	**Unit**	**Value**		
Heating System	Setpoint temperature	21 ◦C	19◦C	23◦C
	Period	From October to June Weekdays and Weekends	From November to April Weekdays and Weekends	From October to mid March Weekdays and Weekends
	Schedule	Until 07.00 (Off)	Until 07.00 (Off)	Until 24.00 (On)
		Until 11.00 (On)	Until 11.00 (On)	
		Until 18.00 (Off)	Until 18.00 (Off)	
		Until 23.00 (On)	Until 23.00 (On)	
		Until 24.00 (On)	Until 24.00 (50%)	
	Period	All other days	All other days	All other days
	Schedule	Until 24.00 (Off)	Until 24.00 (Off)	Until 24.00 (50%)
Cooling System	Setpoint temperature	25◦C	off	23◦C
	Period	From June to October Weekdays and weekends	off	From June to October Weekdays and weekends
	Schedule	Until 12.00(Off)	off	
		Until 20.00 (On)	off	Until 12.00 (off)
		Until 24.00 (Off)	off	Until 24.00 (On)
	Period	All other days	off	All other days
	Schedule	Until 24.00 (0%)	off	Until 24.00 (100%)
DHW (Domestic Hot Water)	Amount (L)	60 L (person/day)	50 L	100 L
Natural ventilation	ACH (Air Change Per Hour)	0.75	1	Off
Ventilation (infiltration)	ACH (Air Change Per Hour)	0.1	0.1	0.1
Lighting	Illuminance (lux)	300	300	300
	Installed power (W/m²)	7.5	7.5	7.5
	Period	Weekdays and weekends	Weekdays and weekends	Weekdays and weekends
	Schedule	Until 07.00(Off)	Until 07.30 (10%)	Until 07.30 (10%)
		Until 18.00 (30%)	Until 19.00 (0%)	Until 19.00 (0%)
		Until 19.00 (50%)	Until 23.00 (100%)	Until 24.00 (100%)
		Until 23.00 (100%)	Until 24.00 (25%)	
		Until 24.00 (50%)		
	Period	All other days	Weekends and holidays	Weekends and holidays
	Schedule	Until 24.00 (0%)	Until 24.00 (25%)	Until 24.00 (50%)

Schedules	San Sebastian	Sc 0_0 (CTE [49])	Sc 1_1 (Economic)	Sc 1_2 (Wasteful)
Parameter	**Unit**	**Value**		
Equipment and Appliances	Installed Power (W/m²)	4.4	4.4	6
	Period	Weekdays and weekends	Weekdays and weekends	Weekdays and weekends
	Schedule	Until 07.00(10%)	Until 07.00(10%)	Until 08.00(25%)
		Until 18.00 (30%)	Until 07.30(25%)	Until 18.00 (100%)
		Until 19.00 (50%)	Until 19.00 (10%)	Until 21.00 (10%)
		Until 23.00 (100%)	Until 24.00 (75%)	Until 24.00 (75%)
		Until 24.00 (50%)		
	Period	All other days	All other days	All other days
	Schedule	Until 24.00 (0%)	Until 24.00 (0%)	Until 24.00 (0%)

Table 13 Brussels Base Scenario (Author)

Schedules	Brussels	Sc 0_0 (CTE [49])	Sc 2_1 (Economic)	Sc 2_2 (Wasteful)
Parameter	**Unit**	**Value**		
Occupancy	People/m² (living area)	0.03	0.03	0.01
	Period	Weekdays and weekends	Weekdays and weekends	Weekdays and weekends
	Schedule	Until 07.00 (100%)	Until 07.30 (100%)	Until 18.00 (100%)
		Until 15.00 (25%)	Until 17.00 (0%)	Until 21.00 (0%)
		Until 23.00 (50%)	Until 24.00 (100%)	Until 24.00 (100%)
		Until 24.00 (100%)		
	Period	All other days	All other days	All other days
	Schedule	Until 24.00 (0%)	Until 24.00 (0%)	Until 24.00 (75%)
Heating System	Setpoint temperature	21 ◦C	19◦C	23◦C
	Period	From 30 September to 31 May Weekdays and weekends	From November to April Weekdays and weekends	From November to mid March weekdays and weekends
	Schedule	Until 07.00 (Off)		
		Until 11.00 (On)	Until 06.00 (Off)	Until 06.00 (Off)
		Until 18.00 (Off)	Until 08.00 (on)	Until 08.00 (On)
		Until 23.00 (On)	Until 18.00 (Off)	Until 17.00 (Off)
		Until 24.00 (On)	Until 24.00 (100%)	Until 24.00 (100%)
	Period	Weekends and all other days	Weekends and Holidays	Weekends and Holidays
	Schedule	Until 24.00 (0%)	Until 24.00 (0%)	Until 24.00 (0%)
Cooling System	Setpoint temperature	25◦C	Off	23◦C

Schedules	Brussels	Sc 0_0 (CTE [49])	Sc 2_1 (Economic)	Sc 2_2 (Wasteful)
Parameter	**Unit**	**Value**		
	Period	From June to October Weekdays and weekends	Off	From May to November
	Schedule	Until 12.00(Off)	Off	Until 12.00(Off)
		Until 20.00 (On)	Off	Until 20.00 (On)
		Until 24.00 (Off)	Off	Until 24.00 (Off)
	Period	All other days	Off	All other days
	Schedule	Until 24.00 (0%)	Off	Until 24.00 (0%)
DHW (Domestic Hot Water)	Amount (L)	60 L (person/day)	50 L	100 L
Natural ventilation	ACH (Air Change Per Hour)	0.75	75	0.75
Ventilation (infiltration)	ACH (Air Change Per Hour)	0.1	0.1	0.1
Lighting	Illuminance (lux)	300	300	300
	Installed power (W/m²)	7.5	7.5	7.5
	Period	Weekdays		
	Schedule	Until 07.00(Off)	Until 07.30 (10%)	Until 07.30 (10%)
		Until 18.00 (30%)	Until 18.00 (0%)	Until 18.00 (25%)
		Until 19.00 (50%)	Until 23.00 (75%)	Until 23.00 (100%)
		Until 23.00 (100%)	Until 24.00 (25%)	Until 24.00 (75%)
		Until 24.00 (50%)		
	Period	All other days		
	Schedule	Until 24.00 (0%)		
Equipment and Appliances	Installed Power (W/m²)	4.4	4.4	4.4
	Schedule	Weekdays and weekends	Until 07.00(10%)	Until 08.00(25%)
		Until 07.00(10%)	Until 07.30(25%)	Until 18.00 (100%)
		Until 18.00 (30%)	Until 19.00 (10%)	Until 21.00 (50%)
		Until 19.00 (50%)	Until 21.00 (50%)	Until 24.00 (75%)
		Until 23.00 (100%)	Until 24.00 (75%)	
		Until 24.00 (50%)		
	Period	All other days		
	Schedule	Until 24.00 (25%)		

Table 14 Istanbul Base Scenario (Author)

Schedules	Istanbul	Sc 0_0 (CTE [49])	Sc 3_1 (Economic)	Sc 3_2 (Wasteful)
Parameter	**Unit**	**Value**		
Occupancy	People/m² (living area)	0.03	0.03	0.01
	Period	Weekdays	Weekdays	Weekdays
	Schedule	Until 07.00 (100%)	Until 08.00 (100%)	
		Until 15.00 (25%)	Until 19.00 (25%)	
		Until 23.00 (50%)	Until 24.00 (100%)	Until 24.00 (100%)
		Until 24.00 (100%)		
	Period	Weekends and Holidays		
	Schedule	Until 24.00 (75%)		
Heating system	Setpoint tempera-ture	21 ◦C	19◦C	23◦C
	Period	From 30 Septem-ber to 31 May Weekdays	From November to April	From mid October to May
	Schedule	Until 07.00 (Off)	Until 06.00 (off)	Until 24.00 (on)
		Until 11.00 (On)	Until 07.00 (on)	
		Until 18.00 (Off)	Until 19.00 (50%)	
		Until 23.00 (On)	Until 24.00 (on)	
		Until 24.00 (On)		
	Period	Weekends and Hol-idays		
	Schedule	Until 24.00 (0%)		
Cooling system	Setpoint tempera-ture	25◦C	27 ◦C	25◦C
	Period	From June to Octo-ber	off	From June to No-vember
	Schedule	Until 12.00(Off)	off	Until 12.00(Off)
		Until 20.00 (On)	off	Until 20.00 (On)
		Until 24.00 (Off)		Until 24.00 (0.5)
	Period	All other days		
	Schedule	Until 24.00 (0%)		
DHW (Domestic Hot Water)	Amount (L)	50 L	60 L	110 L
Natural ven-tilation	ACH (Air Change Per Hour)	0.75	0.75	0.75
Ventilation (infiltration)	ACH (Air Change Per Hour)	0.1	0.1	0.1
Lighting	Illuminance (lux)	300	200	300
	Installed power (W/m²)	7.5	7.5	7.5

Schedules	**Istanbul**	**Sc 0_0 (CTE [49])**	**Sc 3_1 (Economic)**	**Sc 3_2 (Wasteful)**
Parameter	**Unit**	**Value**		
	Schedule	Weekdays and weekends	Weekdays and weekends	Weekdays and weekends
		Until 07.00(Off)	Until 07.00 (Off)	Until 07.00 (10%)
		Until 18.00 (30%)	Until 08.00 (10%)	Until 08.00 (30%)
		Until 19.00 (50%)	Until 19.00 (0%)	Until 19.00 (25%)
		Until 23.00 (100%)	Until 23.00 (100%)	Until 23.00 (100%)
		Until 24.00 (50%)	Until 24.00 (25%)	Until 24.00 (50%)
	Period	Weekends	Weekends	Weekends
	Schedule	Until 24.00 (0%)	Until 24.00 (0%)	Until 24.00 (0%)
Equipment and Appliances	Installed Power (W/m²)	4.4	4.4	6
	Schedule	Weekdays	Until 08.00(10%)	Until 08.00(25%)
		Until 07.00(10%)	Until 19.00 (30%)	Until 19.00 (75%)
		Until 18.00 (30%)	Until 23.00 (75%)	Until 21.00 (100%)
		Until 19.00 (50%)	Until 24.00 (50%)	Until 24.00 (75%)
		Until 23.00 (100%)		
		Until 24.00 (50%)		
	Period	Weekends		
	Schedule	Until 24.00 (0%)		

4.6 Results

The results are conducted at DesignBuilder in kWh/m² and processed at Microsoft Excel and Microsoft Power BI [72] software. The buildings have different base areas thus, perceiving the results in kWh/m² instead of kWh is more precise to make comparisons. The results should be way with the legend below:

- SS: San Sebastian
- BR: Brussels
- IST: Istanbul
- Low: Low thermal quality
- Opt: Optimal thermal quality (Based on the regulations of the specific country)
- High: High thermal quality (Covers more than the regulation necessities)
- SC_0: Base Scenario
- SC_1_1_: San Sebastian Economic Scenario
- SC_1_2_: San Sebastian Wasteful Scenario
- SC 2_1_: Brussels Economic Scenario

- SC_2_2_: Brussels Wasteful Scenario
- SC_3_1_: Istanbul Economic Scenario
- SC_3_2_: Istanbul Wasteful Scenario

4.6.1 Monthly Results

The main evaluation period of the study is annual, however monthly energy demand data gives the information about the time where and when the highest and lowest heating and cooling demand occurs. Additionally, lighting energy demand shows little deviations due to the solar radiation of different seasons and times of the day.

Figure 13 represents monthly data of heating demand for the base, economic and wasteful scenarios are presented for each three cities. While base, economic, and wasteful scenarios have lower heating demand depending on the scale of the building, for San Sebastian wasteful scenario has the highest demand.

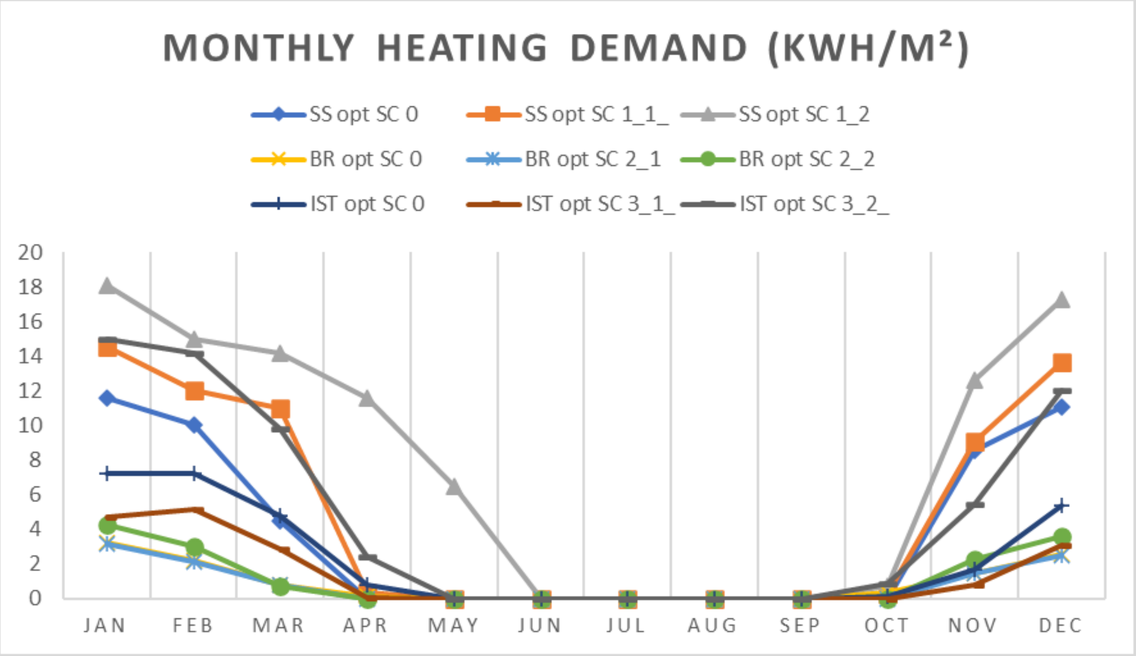


Figure 13 Monthly Heating Demand

The highest cooling demand belongs to the wasteful scenario of Istanbul building with a huge difference from others and it starts earlier and ends later due to the climatic conditions.

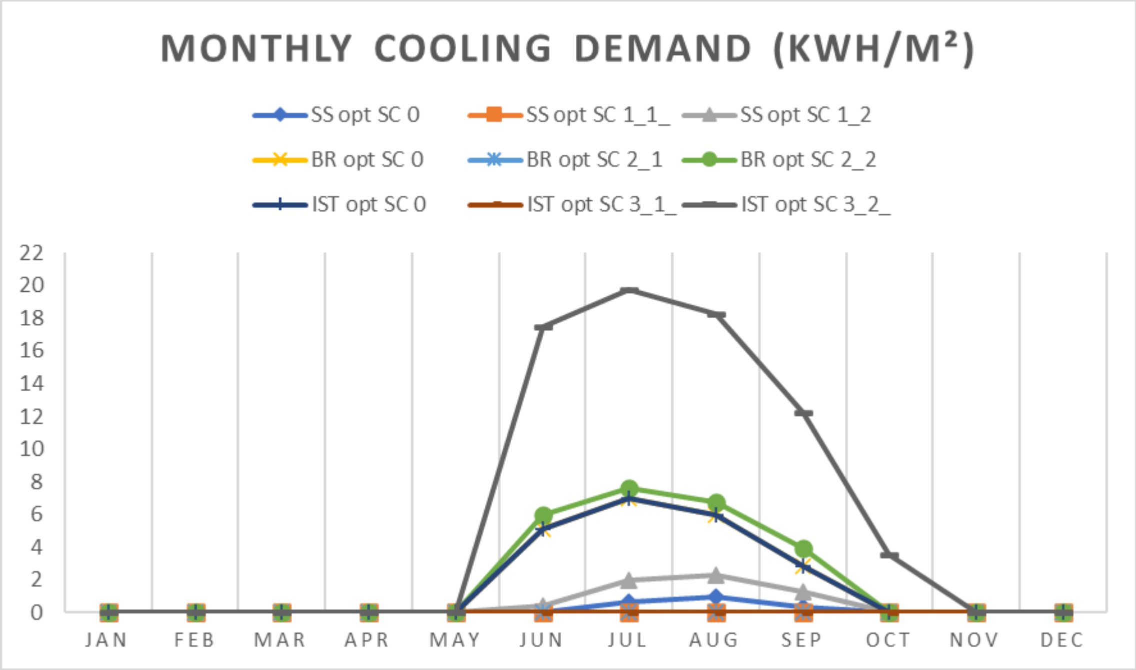


Figure 14 Monthly Cooling Demand

4.6.2 Annual Comparison According to Countries and Building Typologies

The simulations were run on DesignBuilder for the multi-storey building from the Basque Country. The results show that the thermal state of the building is always positive regarding the energy demand for both cooling & heating. Cooling was not necessary for economic scenarios due to the climate where the average temperature is below 20 degrees at summers in San Sebastian [60] and because of the thermal state of the building. More importantly, the effect of user behavior is readable from Figure 15, 16, and 17 below; while economic users, SC_1 has always the lowest in their thermal condition cluster, wasteful occupants SC_2 has always the highest use of energy. Also, the results show that the demand for lighting and equipment are almost at the same amount for the same location & buildings` scenario family while heating and cooling always changes.

Figure 14 shows that the demand rate for the Multi-Storey building at San Sebastian runs between the 0 to 300 kWh/m² range. While for the economic scenarios; the demand is the lowest of all, base scenarios have an optimum demand at the 200-kWh range and for wasteful scenarios having a 24 hour on Heating system decreases the energy demand which disproves the dependency to only user behavior and shows that a wasteful scenario with a high-quality building might function in a better-economic way. While an economic occupant behavior`s heating setpoint temperature is 19°C for all, for wasteful scenarios it is 23°C, thus heating demand change only depends on the time used but not the arranged setpoints for different buildings and climates.

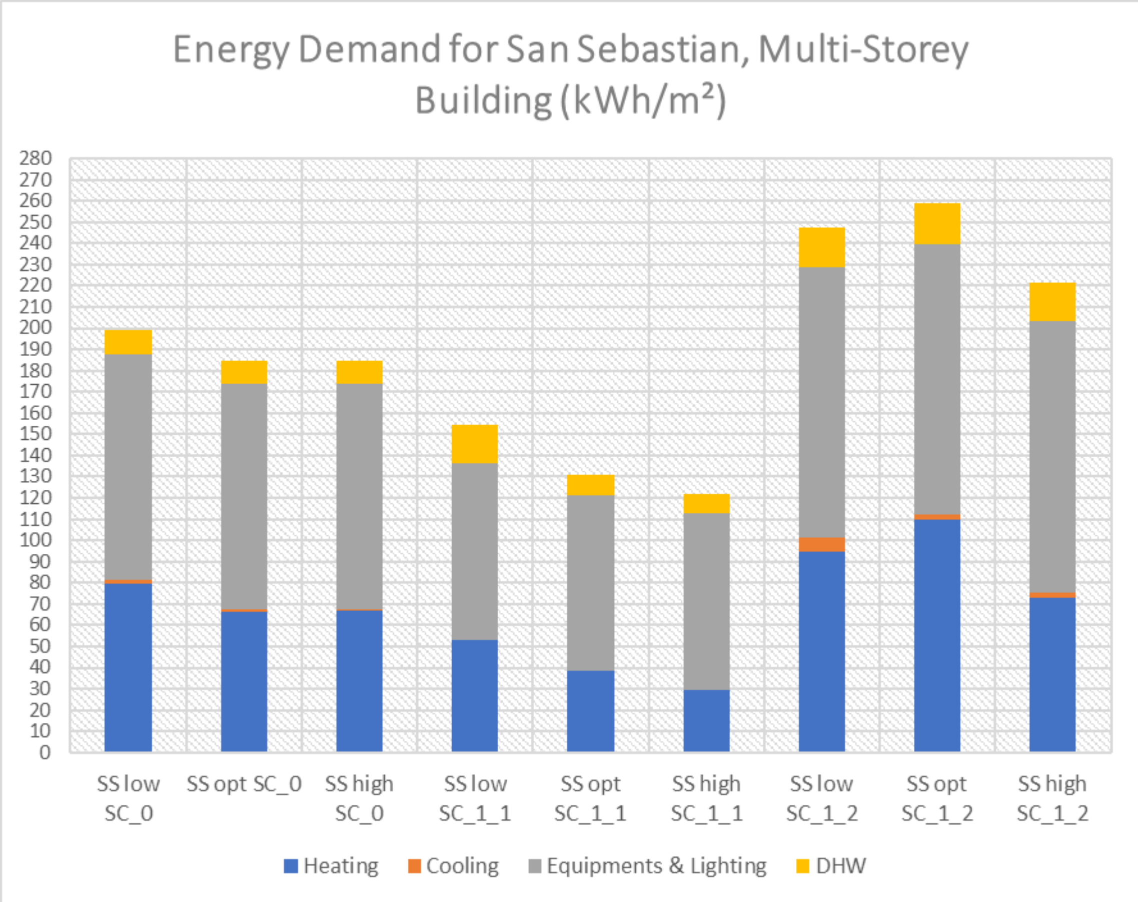


Figure 15 Scenario Results for San Sebastian, Multi-Storey Building

Unlike Figure 17 where the lighting increases in a high thermal condition building, Figure 16 proves the direct proportion of the research question. The deviation at Figure 17 can be reasoned due to the increased use of lighting if the improved glazings have low solar transition.

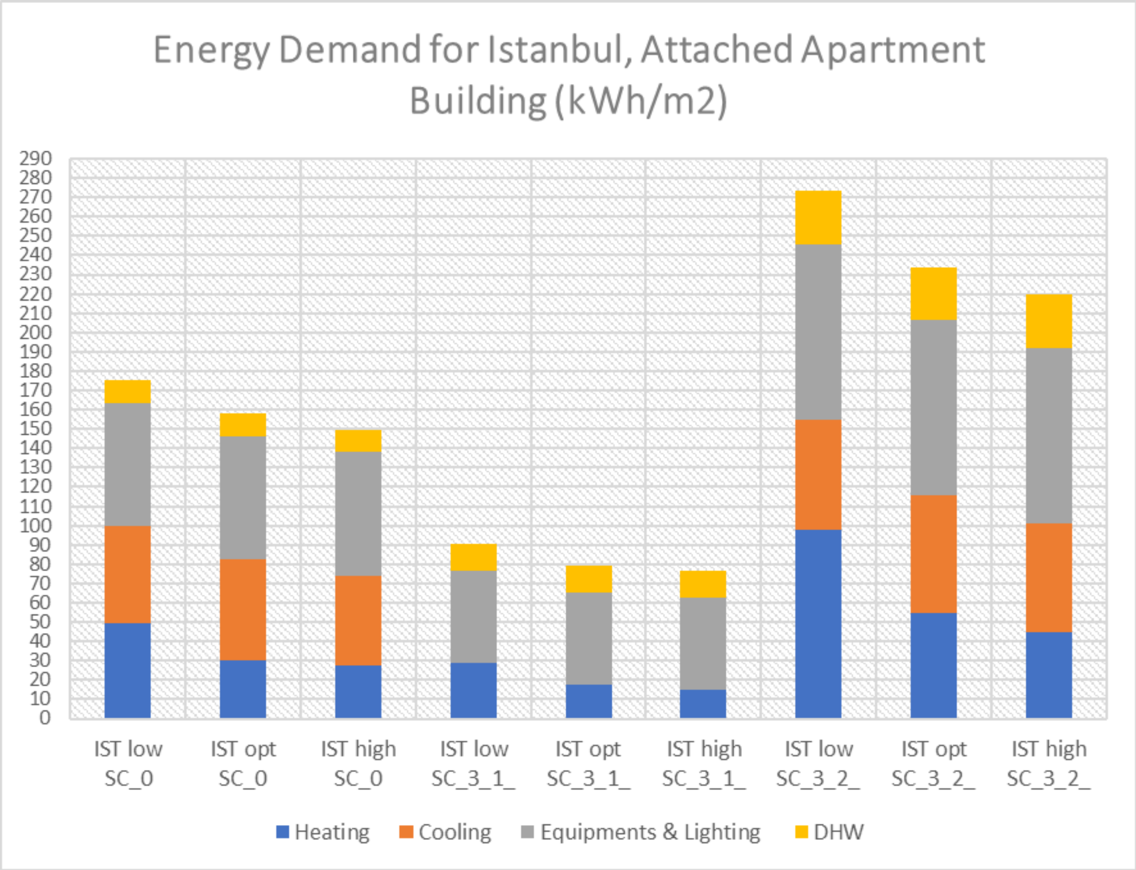


Figure 16 Scenario Results for Attached Apartment Building, Istanbul

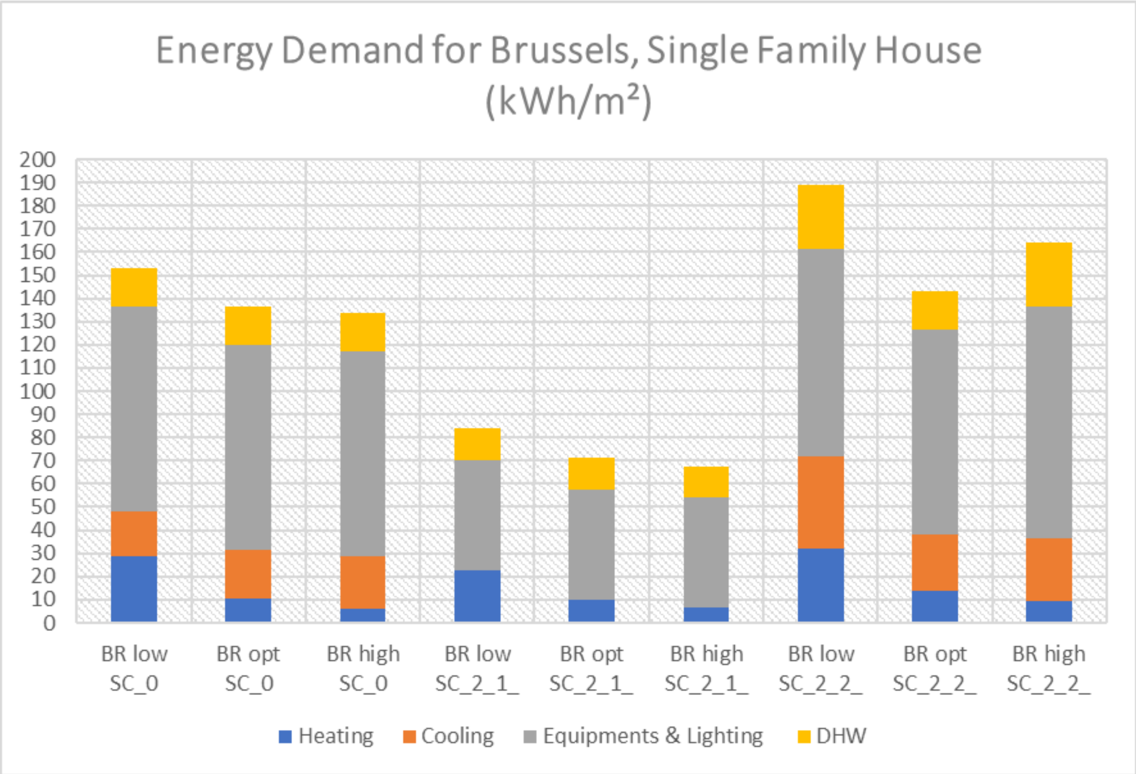


Figure 17 Scenario Results for Single-Family House, Brussels

4.6.3 Annual Comparison According to the Scenarios

As seen from Figure 17, except for some scenarios the more the buildings thermal situation enhances, the more the energy demand decreases in heating and cooling. Additionally, where economic users have low energy demand, wasteful occupants have higher energy demand. In San Sebastian, optimal and high thermal quality base scenarios; the effect of refurbishment was null when user behavior was the same. The results show that the impact of user behavior is having a direct proportion with energy demand.

Figure 18 Comparison according to the scenarios Economic and Wasteful

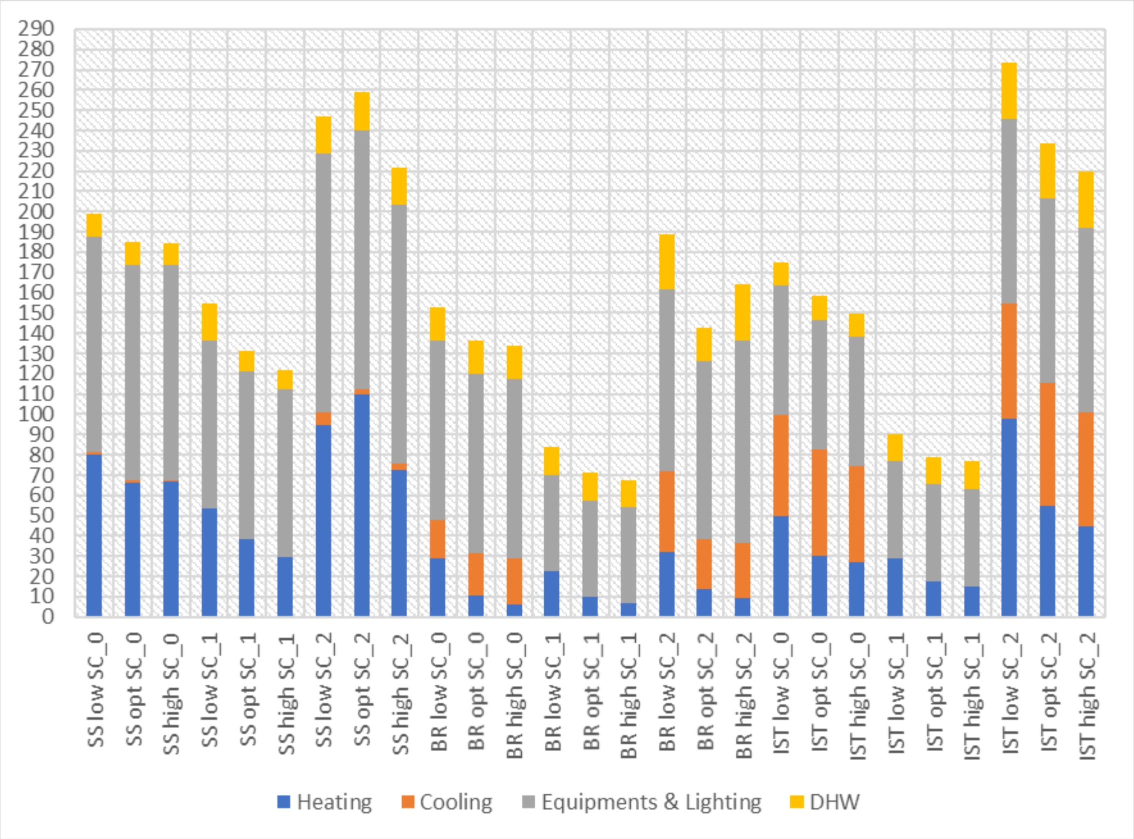


Figure 19 shows the singular demands of energy as seen from it the highest range always belongs to Equipment & Lighting while the lowest mostly belong to the Cooling demand following the DHW and Heating. The highest demand gap belongs to the Heating demand in between 0 to 100 kWh/m². The change depends on different reasons as climate, peak seasons, building thermal quality, and use of equipment. Additionally, internal solar gains, surrounding shadowing elements as other buildings effects the energy demands but are not evaluated in this study.

The highest energy demand for Equipment and Lighting and around 130 kWh/m², for Heating this is around 110 kWh/m², Cooling 60 kWh/m² and 30 kWh/m² for DHW at wasteful scenarios. The lowest for Equipment & lighting is around 50 kWh/m² range for economic scenarios, 10 kWh/m² for CTE base scenario, 0 for Cooling at economic scenarios and 10 kWh/m² for DHW.

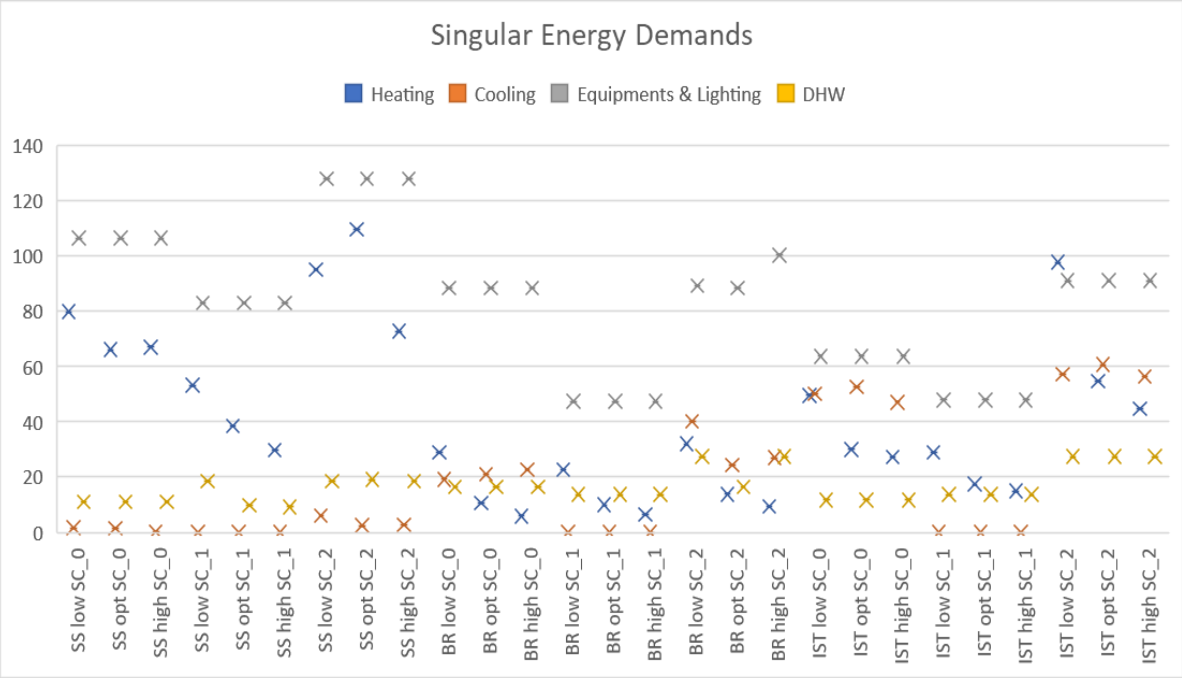
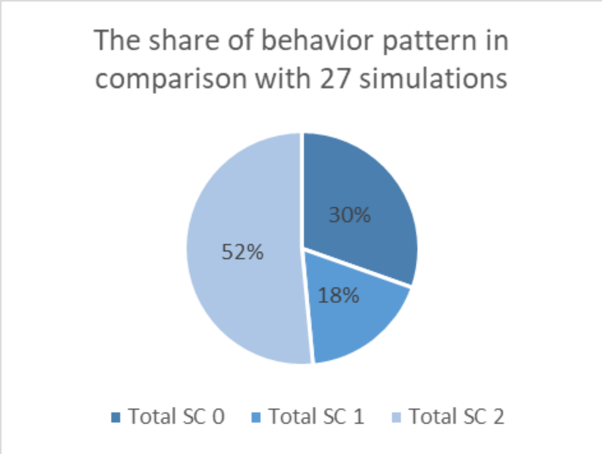


Figure 19 Energy Demands of Heating, Cooling, Equipment & Lighting and Domestic Hot Water (kWh/m²)

Please see Figure 22 in the Appendix chapter to further evaluate all 2 sets of simulation, 63 simulations of total energy demand in an ascending array. As it can be seen the most demanding combinations are low thermal quality buildings with wasteful, SC_2 scenarios. Also, the bigger the building gets the demand gets higher. The range of demand is between 0 to almost 275 kWh at the maximum in total energy demand.

4.7 Share

Figure 20 represents the deviation between the two simulations sets: the first and second set of simulation results. It is interesting that meantime the result of the crosswise set is considerably higher than the first set of simulations; the share of comparison of the scenarios has a quite considerable deviation.



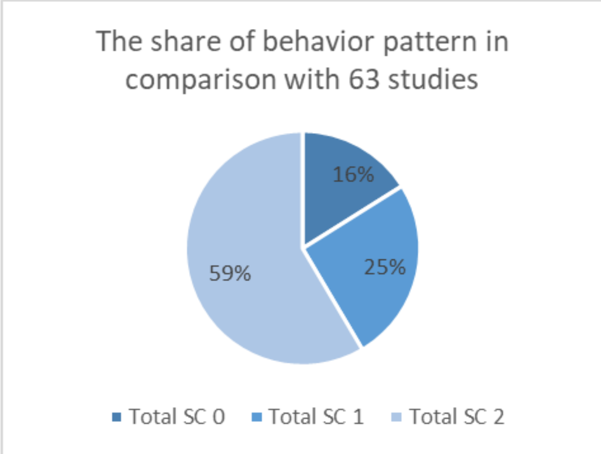
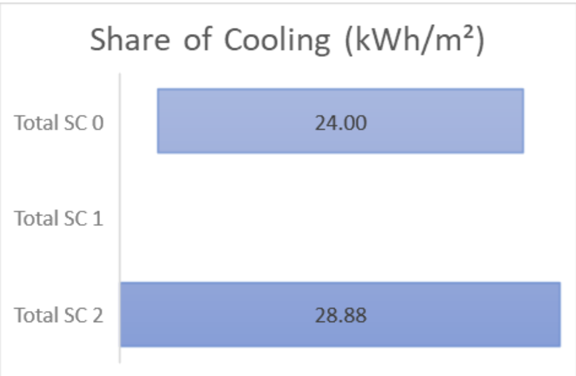


Figure 20 The deviation between the two sets of simulation

For the first set of simulation which consists of 27 simulations, while demand for base scenarios is around 1475 kWh/m² range, for economic scenarios it is 875 kWh/m2 and for the wasteful scenarios 2500 kWh/m². An economic scenario is around 40% lower compared to a base scenario and wasteful occupant has an average higher value than a base scenario at almost 60%.



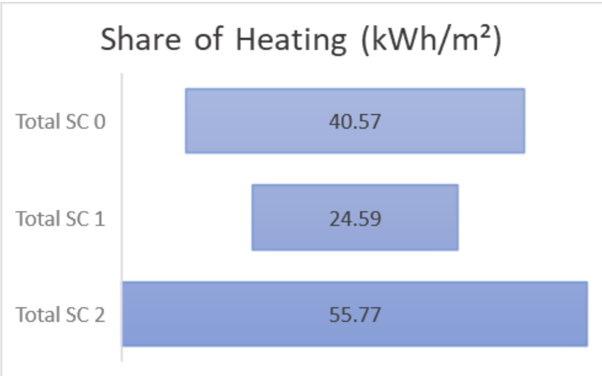


Figure 21 Average Demand of Cooling and Heating between Base, Economic and Wasteful scenarios

The most critical part of energy demand belongs to the heating and cooling loads. According to Figure 21, while average cooling demand doesn`t change a lot in comparison with the wasteful and base scenario for heating the gap between the base and wasteful scenario is higher in kWh/m². There might be different possible reasons for that as scenarios are not designed with an order so, wasteful scenarios can be more consuming.

5 Conclusions & Discussion

The above results confirm the research question that occupant behavior affects energy demand and the control of this depends on the occupants. Wasteful scenarios and thermally poor conditions have higher energy demand; however, there are some expectations. Turner and Frankel highlight the importance of building refurbishment; if there is a building that is performing well thermally, it is the responsibility of the occupant to make savings [73]. When a building has a good thermal quality, heating and cooling demand can be almost at an unimportant level. Nevertheless, the study shows that the thermal condition of the building is significant to complete the necessary regulations. An examination of the same thermally conditioned building shows the importance of occupant behaviour in a clearer way. Moreover, climatic conditions play an important role, such as San Sebastian which has an oceanic climate does not need to be cooled in summer generally. On the other hand, the same building would need cooling needs if it is in Istanbul with the same building properties.

The results for domestic hot water and equipment demand do not generally depend on external variables, that`s because they only depend on the hour of use unlike the heating and cooling demand. However, lighting demand has small fluctuations in case of glazing retrofitting.

The motivation that led to this research project was to examine the fast-changing environment of energy consumption and those responsible to reduce the effects of consumption after identifying the supplier to create low-energy districts and cities. As mentioned in the introduction part, it is well explained that cities nowadays have the highest share of energy consumption due to the energy consumption at buildings. These changes in urban areas lead to many environmental and ecological damages. Nevertheless, this is a highly complex structure of different variables. The influence of human`s behavioral patterns are non-deniably important for energy consumption at each level from appliances to buildings and districts, yet for bigger scales, the analysis of the effects of human behavior is quite complex. Besides, a conference at IDOM was inspiring, which was showing how different occupants were influencing energy consumption by managing the manual thermostats at the same time. As for this study, building level evaluation was more appropriate to study the impact of occupant behavior; even though there are many studies conducted in the scientific field. In this way, this study lacks originality while raising an important and necessary point. To achieve the objectives, different scenarios of utility schedules were set on DesignBuilder. The aim was to take the comparison of the results of these schedules to show the impact of an occupant. In this stage, some generalizations and assumptions were made that decreases the accuracy. The schedules were again based on the existing Spanish Technical Code regulations; still, they are not detailed enough to show, weekend activities, vacations, annual vacations of the residents, their changing occupancy rates, the presence of guests, extreme situations in their lives such as pandemic, unemployment, birth, death etc. Therefore, this schedule represents only a "normal" and generalized time of the occupants` lives. Two different occupant typology was "economic" and "wasteful". In the end, results were taken from over 60 simulations of different combinations of thermal behavior of the buildings, building typology, climate, user behavior. The comparison of these different combinations indicates the importance of the variables by the increase and decrease yet it is all open for comments to understand which variable was more effective.

Another weak part was the determination of the schedules as wasteful and economical, which is also open to the author`s criticism. For example, as shown in several examples above, setting "heating on for 24 hours" as a wasteful scenario ended up being an economic behavior to keep the indoor heat at a stable level.

All 3 buildings are existing buildings and sites, but there is insufficient data on environmental factors and buildings. Collecting more detailed data would be a great improvement to carry the study further.

From an academic perspective, this study was well thought out to understand the phases of an academic research study and a more comprehensive study is needed. Finally, not always the aimed level of accuracy happens; during the study due to several reasons, some assumptions had to be made. Nonetheless, the experience confirmed the belief behind the research in general with the exception of some situations.

The results were expected; however, it is interesting to note that the second set of scenarios have a higher energy demand than the first set of scenarios. This is interesting because the schedules are not designed for specific situation. This experience would lead to analyze bigger scale systems like district levels. For this, more complex simulations might require faster and more comprehensive simulation tools.

5.1 Recommendations and Future Study

5.1.1 A Real Life-Occupant Survey Comparison

This study reflects positively on the ideas behind it but should be further explored and evaluated. There are two main issues to focus on; the first is the reality of schedules and the second is the gap between BES and real life. The gap between real-life and building simulation tools still exists even though the study aimed to show the difference. A further study could be making the comparison and study simultaneously with real-life occupants and their user preferences. Building energy simulation tools gives more accurate results as much as detailed data has entered. In this way, it would be possible to decrease the gap between building simulation tools and real-life as well as the increase reality of schedules. This study still contains many generalizations and assumptions about how schedules are structured. It is certain that variables such as work schedules, recreation schedules vary by location, marital status of residents, or their age. A survey about the energy use from the existing occupants and the typology of occupants would be more accurate to design the DesignBuilder data accordingly. This would increase the accuracy of the study to show and differentiate the accountable factors.

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Appendix

Figure 22 Total Demand in an Ascending Array