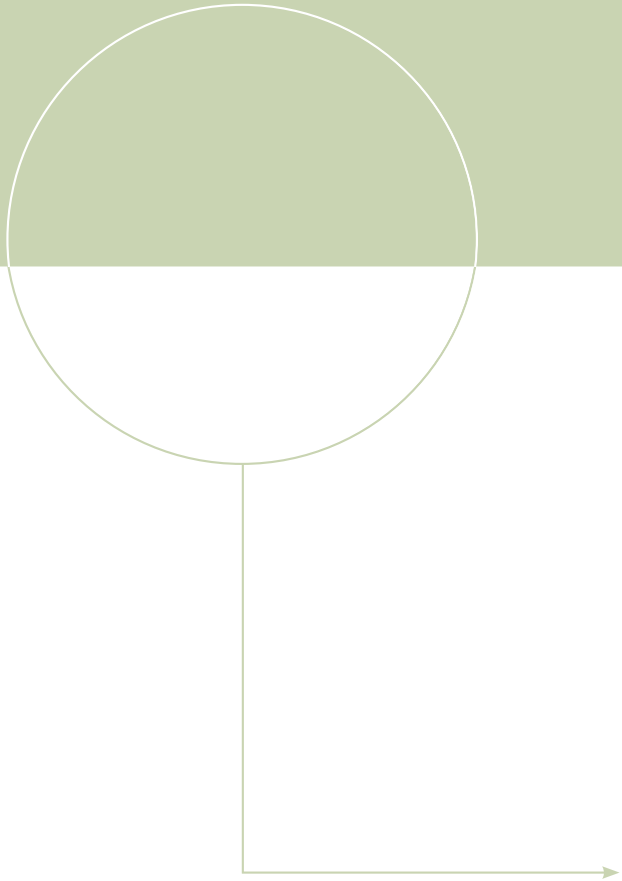

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Narayan Dungana

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Evaluation of the Impact of Microclimatic Parameters on Energy Performance of ZEN with BEPS

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Evaluation of the Impact of Microclimatic Parameters on Energy Performance of ZEN with BEPS

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Abstract

The rapid urbanization has led to formation of complex urban morphologies which have resulted in increase of temperature in cities as compared to nearby rural areas. With urbanization comes the buildings and buildings consume high amount of energy. Therefore, reducing the energy demand of a building is a major focus of study today. One of the ways is through study of the climate at micro-scale level. However, the general practice today is to take the climate data from a typical meteorological weather station without considering the local climate where the building is to be built.

In this regard, this study evaluates the impact of microclimate on building energy demand using building energy performance simulation tool (IDA ICE). NTNU Gløshaugen campus is selected for the study site and Sentralbygg 1 is taken as a representative building. The building is modelled in IDA ICE and simulated using different climatic data. Firstly, the climate of Værnes is used in simulation. The obtained result is compared with the results from the climate of Gløshaugen. It shows that there is a significant difference in energy demand while using the microclimatic data. There is a reduction of about 8.4% of energy demand while using the weather data from Gløshaugen.

Further, the CFD generated weather data is used for one week each in summer and autumn. Two case scenarios are considered for the study, one, the base case scenario where the vegetations, pavements and materials are considered as it is, other the no-vegetation scenario where the vegetation is removed and replaced by concrete. The results show that the base case scenario has lower energy demand in summer case due to the fact that the no-vegetation scenario resulted in additional cooling demand.

On top of that, the climate data from Værnes and Gløshaugen are compared to study differences in terms of temperature, heating degree days, wind velocity and solar radiation. The Gløshaugen campus shows about 2˚C higher temperature than that of Værnes. The heating degree days associated with Værnes weather data is 11% higher than that of Gløshaugen.

Based on the results and findings, relevant recommendations are made for the future energy design in buildings.

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List of Abbreviations

CFD	Computational Fluid Dynamics
IDA ICE	IDA Indoor Climate and Energy
HDD	Heating Degree Days
NTNU	Norwegian University of Science and Technology
UHI	Urban Heat Island
ZEB	Zero Emission Building
ZEN	Zero Emission Neighbourhood

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1. INTRODUCTION

1.1 Research Background

The UN Population Division (2018) estimates that the urban population of developed countries of Europe and North America is more than 78% and is expected to increase to 81% by 2050. This rapid urbanization had led to formation of complex urban morphologies with increased built density, layout and forms. The result of this has generated several challenges in designing climate-resilient urban neighbourhoods. IPCC (2014) states that the global energy consumption in urban area is more than 70% as a result of complex urban morphologies, with most of this driven by building energy demand. This convoluted urban morphology creates a microclimate which is different from the surrounding area.

The past studies have shown that it is of growing importance to take the local climate into considerations when designing a building (Magli et al., 2015; Skelhorn et al., 2016). Anthropogenic heat, solar radiation, urban geometry, vegetation and built-up materials all influence the local thermal and wind patterns, thus affecting the climate context in the neighbourhoods (Santamouris et al., 2001). There is another phenomenon called Urban Heat Island (UHI) which have generated significant increase of cooling demand due to urban overheating (Hirano and Fujita, 2012). This is also a result of urban microclimate.

Despite the advancement of microclimatic models and several past research, the calculation of building energy performance largely overlook the impact of microclimate. Yang (2012) argues that the meteorological boundary conditions adopted in Building Energy Performance Simulations (BEPS) are mainly based on Typical Meteorological Year (TMY) data from weather stations, which are averaged over several years, and this largely ignores the effect of urban surrounding and local climate (Gobakis and Kolokotsa, 2017).

Therefore, this study aims to establish a quantitative evaluation of the impact of microclimate on the energy consumption of buildings through Building Energy Performance Simulations (BEPS).

1.2 Aims and Objectives

The main aim of this study is to evaluate the impact of microclimate on building energy demand using BEPS. The following objectives form the basis of achieving the above stated aim.

- To examine the factors that influence the formation of microclimate.
- To quantify and compare the influence of different scales of climate data on building energy demand.
- To compare and analyze the influence of microclimate on building energy demand through modifications of environments.
- To quantify the benefits of considering the microclimatic parameters in terms of building energy demand.
- To formulate the recommendations for taking microclimatic data into considerations in minimizing the energy demand of a building.

1.3 Research Methodology

This section describes the process of methods used in this study to achieve the research goal. A critical review of the literatures has aided in defining the problem statements and framing the research goals and objectives. The NTNU Gløshaugen campus is selected for the case study site. A representative building is identified from the study site to model and simulate the impact of microclimatic parameters on building energy demand using building energy performance simulation tool (IDA ICE). The climatic data are collected from three different locations based on the proximity to the case study building.

1. Værnes- this is the typical meteorological weather station located about 26km away from the study area.
2. Gløshaugen- this is the campus area and the selected site for the study. The recorded weather data are collected from one of the weather stations.
3. Sentralbygg 1- this is the case study building and the weather data at a point on the facade is collected which is generated through Computational Fluid Dynamic (CFD) analysis performed by a PhD scholar.

The scale of coverage is taken into considerations based on the definitions from Orlanski (1975). A broader division of the climate is presented in table 1.

Table 1: Division of the scales of climate (Orlanski, 1975)

Scale Definition	Radius of coverage (km)	Examples
Macro scale	>2,000	Atmospheric conditions continuing for several days up to a month such as tidal waves.
Meso scale	2 - 2000	Atmospheric conditions continuing for few hours such as thunderstorm.
Micro scale	<2	Atmospheric conditions changing within a minute or an hour such as thermals, plumes, roughness and turbulence, etc.

All these climate data form the main input parameter for simulating the building in IDA ICE. The energy demand, operative temperature and indoor comfort associated with each climate information is compared against each other to assess the impact of microclimate on building energy demand. Finally different recommendations are formulated based on the results obtained. The summary of the methodology is presented in figure 1.

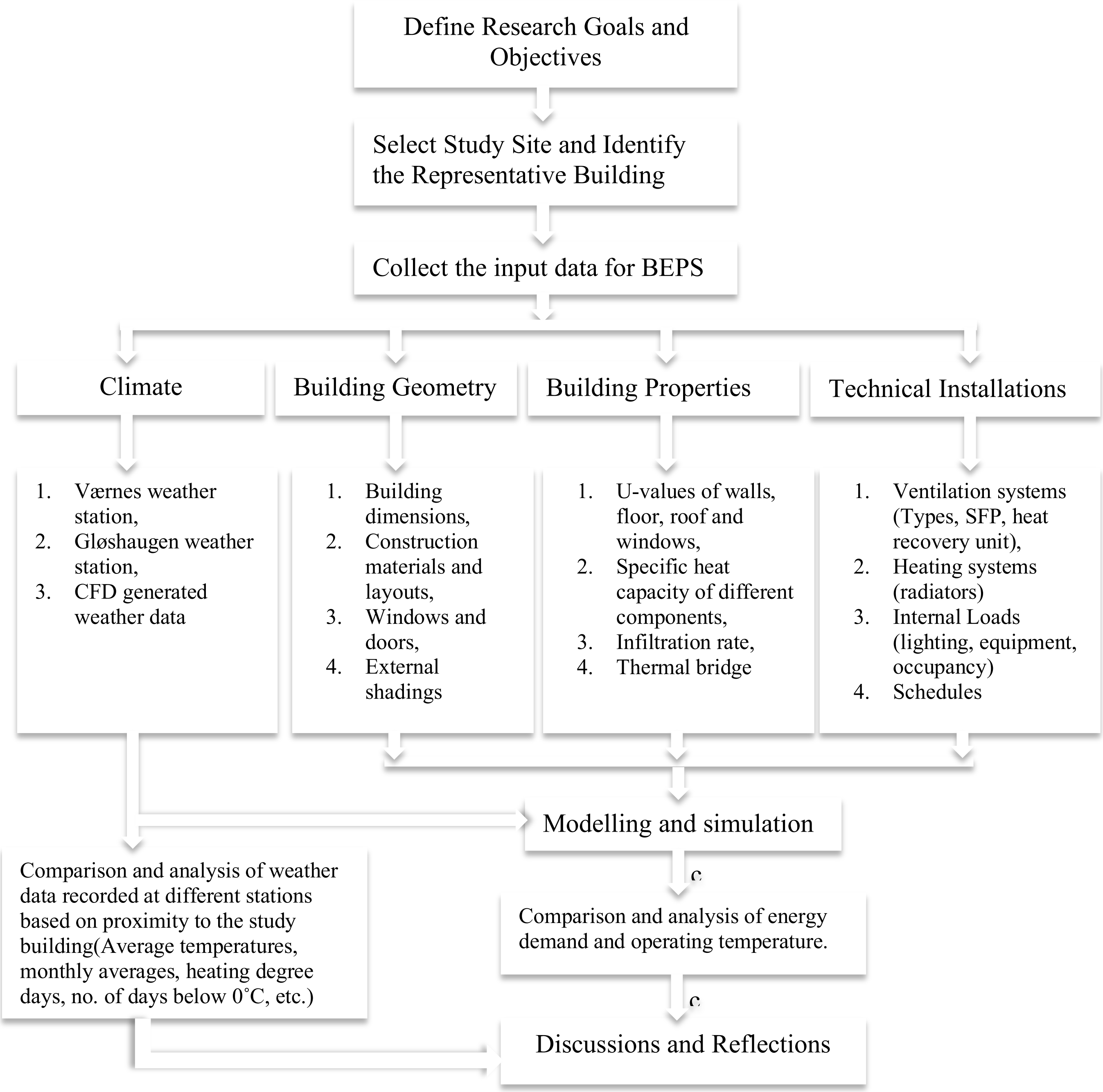


Figure 1: Research Methodology Flow Chart

1.4 Thesis Structure

This thesis consists of six main sections which are briefly explained below.

1. **Introduction**- this section mainly introduces the research background with problem statements, aims and objectives of the study, adopted methodology and limitations of the study.
2. **Theory**- this section walks through the theoretical background of microclimate, factors affecting microclimate and how it affects the building energy demand.
3. **Site Analysis**- this section details the study site selection with analysis of climate, surrounding, materials and buildings. The details of the representative building selected for the study is also presented in this section.
4. **Building Modelling and Simulation**- this section mainly walks through input data collection for building modelling and simulation, zoning of the buildings and creation of different climate files for the simulation process.
5. **Results and Discussions**- the results obtained through climate analysis and simulations are analyzed to evaluate, compare and draw the conclusions on the impact of microclimatic parameters on building energy demand.
6. **Reflections and Conclusion**- this section wraps up the study with critical reflections of the results and their implications on the future building designs along with the limitations and challenges of the study.

2. THEORY

2.1 Introduction to Microclimate

The tendency of urbanization is growing rapidly in the world, both in developing and developed countries. Today, about 55% of world's population live in urban areas and by 2050, it is projected that about 68% will live in urban areas according to World Urbanization Prospects (UN, 2018). It may cause microclimatic changes in these areas. In fact, urbanization is the process by which many people permanently settle in relatively small areas forming cities. According to Tahir et al. (2015) "rapid urbanization can be determined as rapid increase in the number of urban dwellers who need civic amenities at the cost of social, economic and environmental degradation". According to Nelson et al. (2009), the climate change and urbanization cause changes in thermal characteristics of various ecosystems which may consequently induce undesirable effects. According to several studies dealing with side effect of urbanization, one of the main results is increasing regional or microclimatic changes in large cities associated with their surroundings.

Microclimate is a product of several phenomenon acting at urban areas. The cluster of buildings, lack of vegetations, types of materials used in urban structures, amount of anthropogenic activities and formation of street canyons are some of the causes of microclimate. The figure 2 below shows different phenomenon occurring in a city which are the causes of formation of microclimate.

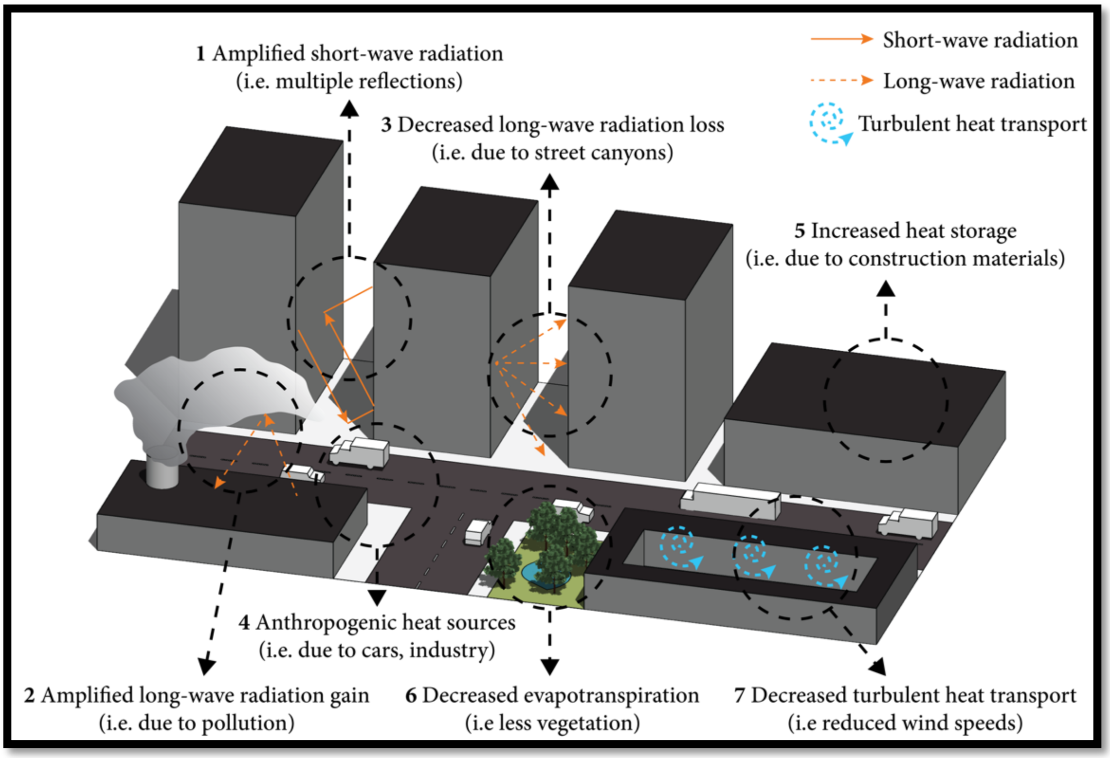


Figure 2: The formation of microclimate (Toparlar, 2018)

2.2 Factors affecting microclimate

2.2.1 Air temperature

Many factors influence the daily increase or decrease of air temperature. At a given site it depends on the wind and the local factors such as altitude, latitude, distance from the sea, sky coverage, rainfall, length of the day and night, presence of water bodies, presence of vegetations etc. (Magu, 2006; Eliab, 2004). According to Magu (2006), “when the wind speed is low, local factors strongly influence on temperature of air close to the ground, while the wind speed is high, the temperature of the incoming air is less affected by the local factors”.

2.2.2 Humidity

Air humidity reflects the amount of water vapour present in the air. In an urban climate, the relation between air temperature and humidity is considered as the main factor that greatly affects the human comfort and health. Manibhai (2013) identified three cases of relations as follows:

Case one, high temperature and high humidity

High temperature and high humidity can cause discomfort if sweat doesn't evaporate, but proper design to provide good air movement by natural ventilation can reduce discomfort.

Case two, low temperature high humidity

On low temperature and high humidity, both the outside surface and human body feel cool because of heat convection from the urban surface and the human body. There is a high possibility of condensation of water vapour occurring on the cooler side of surface leading to the deterioration of the building materials.

Case three, high temperature and low humidity

On dry days, the sweat evaporates quickly, resulting in the cooling of body.

2.2.3 Wind

Wind can be defined as the mass of air that moves above the surface of the earth, mostly in a horizontal direction from an area of high pressure to the area of low pressure (Hyndman, 2010). The main reason for the occurrence of wind is the variations of temperature of Earth's surface, i.e., the variation of the ability of surface materials to absorb the solar radiation. As a result, differences in air pressure are created. Many tools have been developed to study the wind behaviour such CFD. The shape of the buildings, urban configurations, streets, and trees affect the wind speed (Hauda, et al).

2.2.4 Solar Radiation

Solar radiation is considered the main factor that influence microclimatic process. It affects the surface and air temperatures, wind and turbulence, evaporation and transpiration, growth and activities of plant and animals, etc. According to Kumar et al. (1997), 99.8% of the energy at the Earth's surface comes from the sun. The behaviour of the earth's surface materials can be divided into absorbed solar radiation and reflected solar radiation.

The absorbed solar radiation (short-wave radiation such as ultraviolet, visible and short-wave infrared) is the radiation that is heating the land later re-emitted in the form of long-wave infrared. While the reflected solar radiation is the radiation received at the earth's surface and then redirected to the space by reflection (Gurney et al., 1993).

Solar radiation affects the thermal performance of the building. The temperature in the space, object or structure increases due to solar gain. The solar radiation is either absorbed by the opaque elements of the building envelope, then conducted to the indoor spaces or directly reaches the inner wall through the windows and heats them.

2.3 Urban Heat Island (UHI)

With urbanization, the physical structure of an environment changes due to modification of the earth's surface through replacement of the vegetation, open water surface and open land surface with urban infrastructures. These changes will often create variation in the city surface temperatures, influencing the atmospheric air temperatures, leading to the so-called urban heat island (UHI) phenomenon, in which the temperature in the city is higher than that in rural areas (Wong et al., 2008). In most cases, the peak differences between urban and rural temperatures happen during clear nights with light winds, and temperature elevations are commonly about (1–4° Celsius).

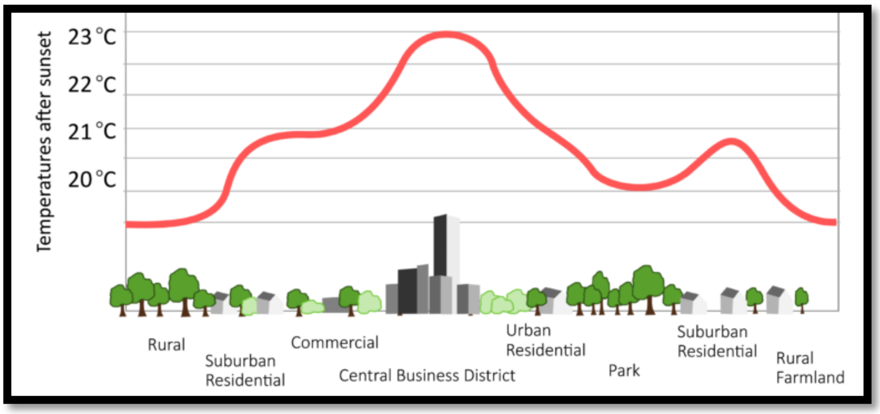


Figure 3: Urban Heat Island Profile (IPCC, 2007)

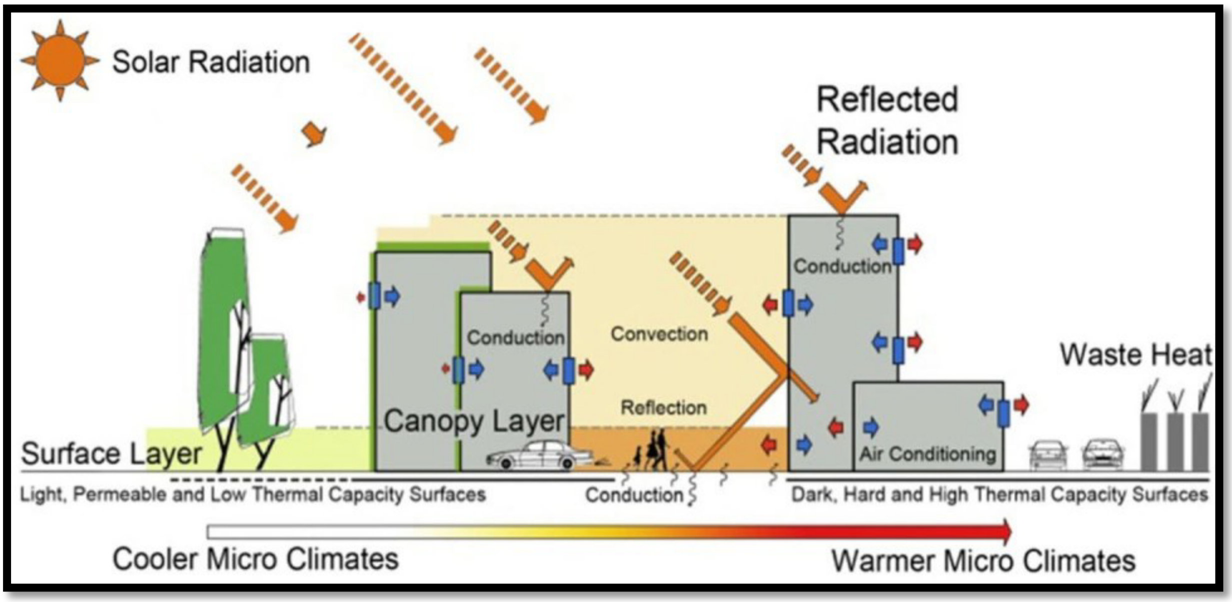


Figure 4: Urban structure, landscape, land-cover and metabolism contribute to the UHI effect (Sharifi and Lehmann, 2015)

2.3.1 Factors Affecting Urban Heat Island

There are several factors contributing to the phenomenon of Urban Heat Island. The table below (table 1) shows some of the main factors affecting UHI.

Table 2: Factors affecting UHI (Sharifi and Lehmann, 2015)

Factors	**Description**
Urban geometric design	It affects the exposure of urban surfaces to sunlight and the consequent heat storage in thermal mass. As a result, it affects heat exchange balance in the built environment
Urban cover and surface materials' thermodynamic specification	Colour, texture, density of materials, and area exposed to sunlight, all these factors can affect the heat absorption and reflection time-rate in the built environment.
Urban landscape and waterscape	It affects photosynthesis and evaporation processes in urban greenery and then consequently contributes to decrease the ambient temperature. It affects heat exchange balance in the built environment.
Urban metabolism and anthropogenic waste heat in cities	It is mainly related to energy consumption for indoor air-conditioning and motorized transportation.

2.4 Properties of Urban Materials

The construction materials properties, either exterior building walls or surrounding matrials affect the thermal performance and energy needed in relation to indoor thermal comfort with regards to their various thermal performance. Determining the thermal performance of any construction materials is of prime importance to determine the heating and cooling load within a building but also outdoor local climate conditions. The thermal performance of any materials is a function of several factors such as thermal conductivity, thermal resistance, emissivity, absorptivity, reflectivity, specific heat capacity, density, etc., which can vary over time due to weather and aging conditions. A broader classification of the construction materials is presented in figure 5.

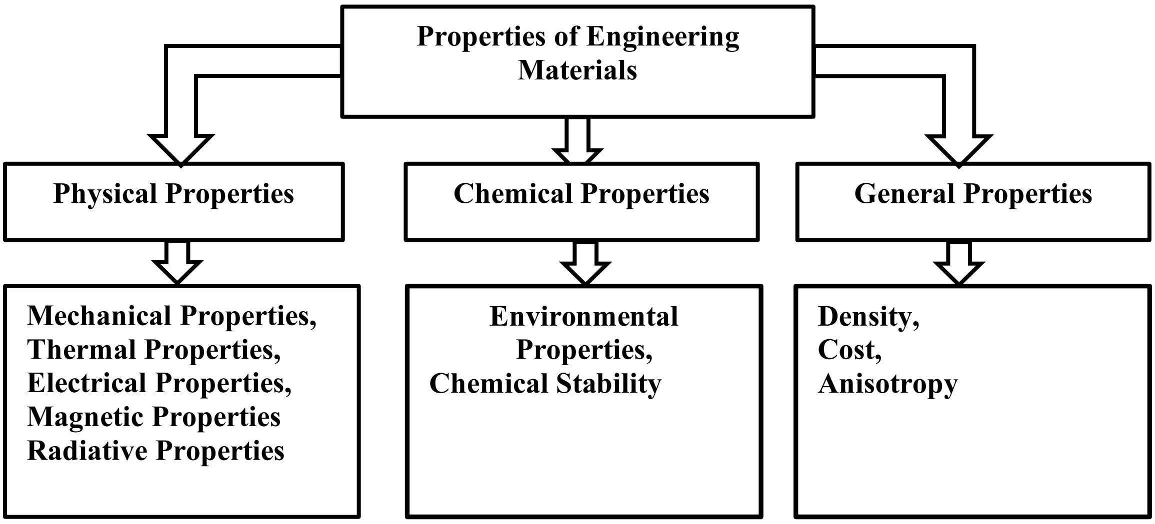


Figure 5 Classification of properties of construction materials (Aran, 2007)

For the purpose of this study, the main focus is on two properties, namely, thermal and optical properties.

2.4.1 Thermal Properties

The thermal properties of the urban materials have a significant impact on the microclimate. Every material used in urban typology has fundamental physical properties that determine their energy performance (Mohammad and Shea, 2013). The thermal properties of materials include thermal conductivity and thermal mass and each one includes a set of factors (Autodesk Education Community, 2015) as presented in figure 6 below.

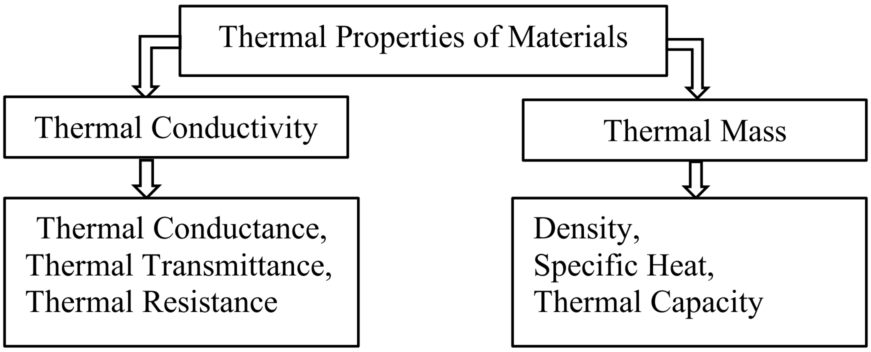


Figure 6: Thermal Properties of Materials (Autodesk Education Community, 2015)

Thermal Conductivity

In physics, thermal conductivity, K value is a thermophysical measure of how much heat is transferred through a material by the conductive flow. It is measured in watts per meter kelvin (W/(m.K)) (Söderholm, 2000). Materials that have a high thermal conductivity are called conductors. They have greater ability to transmit thermal energy, whereas materials of low thermal conductivity are called insulators (Anusavice, 2003).

Thermal transmittance, also known as U-value or U-factor, is the rate of transfer of heat (in watts) through one square meter of a structure, divided by the difference in temperature across the structure. It is expressed in watts per square meter kelvin, or W/m^2K. Well-insulated parts of a building have a low thermal transmittance whereas poorly insulated parts of a building have a high thermal transmittance (Dubai municipality, 2017).

Thermal Mass

Thermal mass is a material capacity to absorb, store and release heat over time. For example, the concrete or any other heavy material has a high capacity to store heat and is known as high thermal mass materials. Although the specific heat storage capacity of the wood is higher than that of concrete, the density and total amount of material is less, it is a light construction which has low thermal mass in total. It is a key cause in dynamic heat transfer exchanges within a building (thermal lag). Density, specific heat and thermal capacity are the main factors affecting thermal mass of a material (Grondzik et al., 2014).

2.4.2 Radiative (Optical) Properties of Materials

Radiative properties of materials describe the interactions between the solar radiation and the materials. The radiative property is a function of two main characteristics of a material-albedo and emissivity.

Albedo

Albedo or reflection coefficient "indicates the fraction of short-wave radiation that is reflected from land surfaces into the atmosphere" (Filho et al., 2016). It is the characteristics of the surfaces that decide their ability to reflect or absorb solar radiation falling on them. The rest of radiation which is not reflected is absorbed (or transmitted) by the surface, therefore, contributes to the rise of surface temperature. Different surfaces have different albedo values, for example, oceans, lakes, and forests reflect small portions of the incident solar radiation and have low albedos, whereas, snow, sea ice, and deserts reflect higher amount of solar radiation because of high albedos. The albedo value depends on the spectral and angular distributions of the incident light which are controlled by atmospheric composition and the direction of the beam of light from the sun.

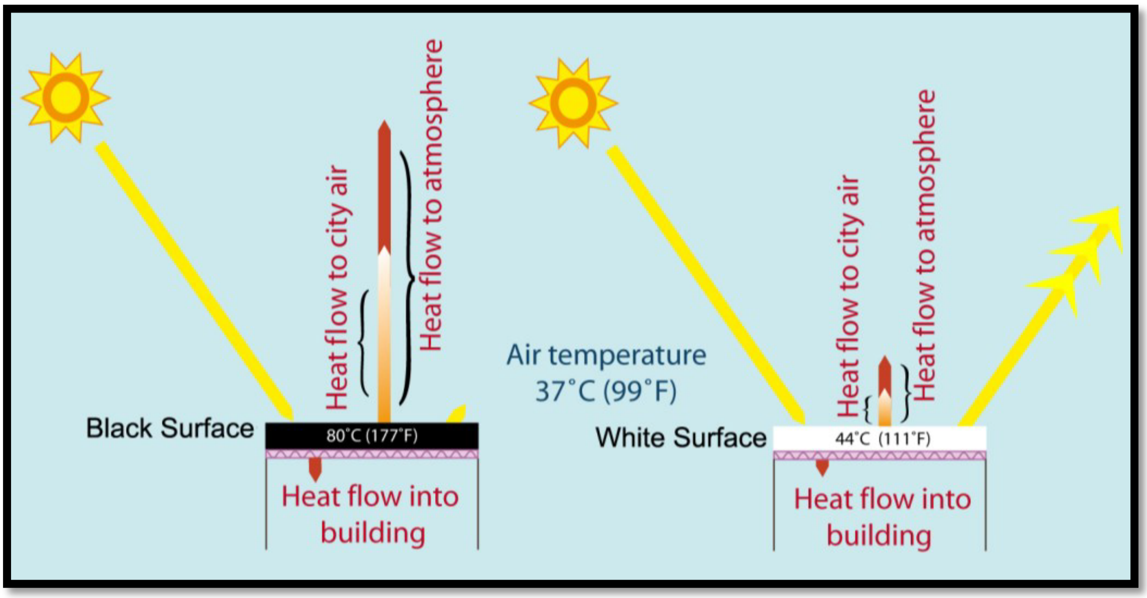


Figure 7: The difference between high albedo surface and low albedo surface (Chao, 2010)

When a surface albedo is equal to 0 it doesn't reflect any amount of radiation, while when it is 1 all the incoming radiation is reflected to the atmosphere (Coakley, 2003; Filho et al., 2016).

Emissivity

Emissivity is the surface characteristic used to measure the ability of a surface to emit longwave radiation. It is considered as an important factor which helps to indicate the temperature of the surface. Emissivity can have a value from 0 (shiny mirror) to 1.0 (perfectly black body). It is the ratio between the energy radiated by a material and the energy radiated by a blackbody at the same temperature. For a given wavelength, the absorption coefficient of a material is equal to its emissivity (Salvaggio et al., 2009). The emissivity and reflectance of some of the common materials are presented in figure 8.

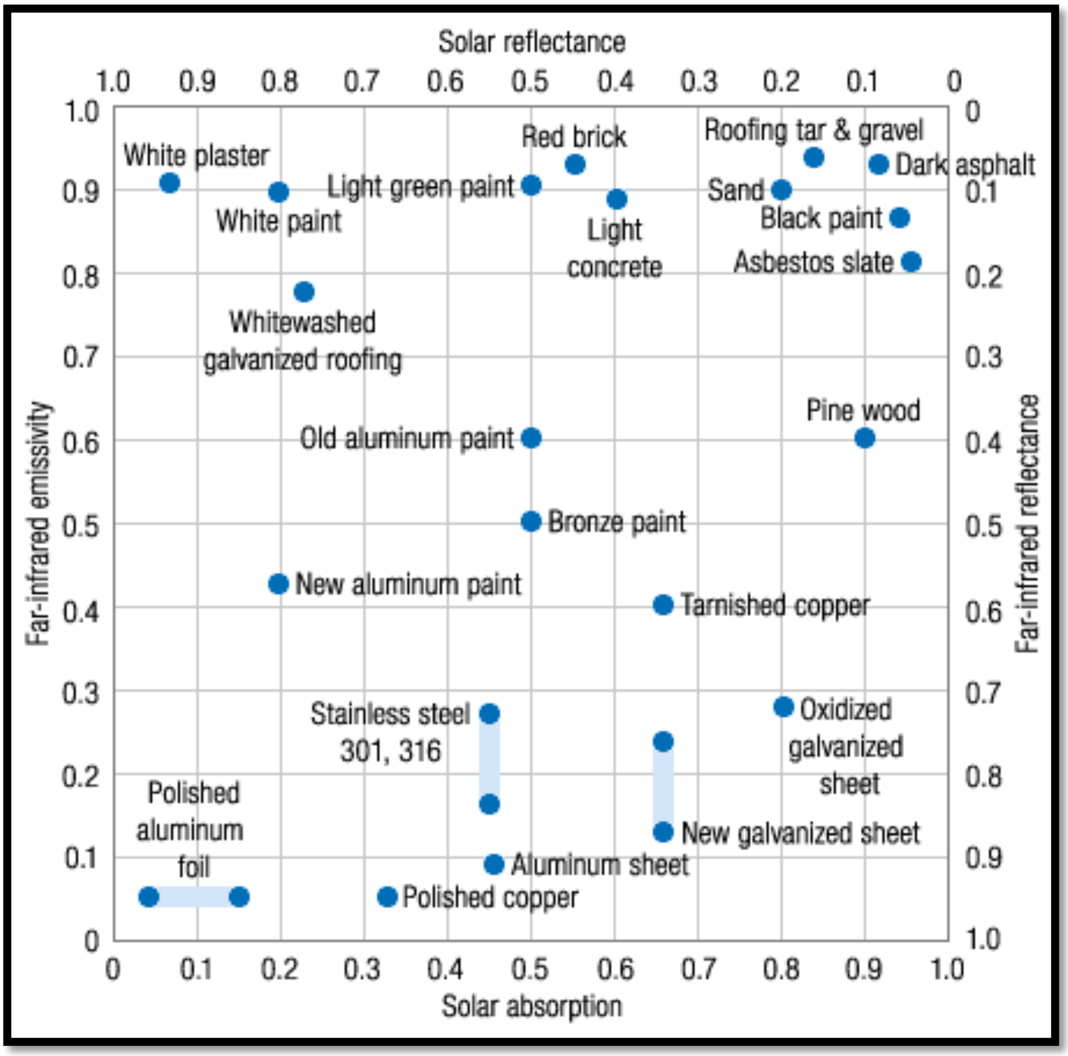


Figure 8: Emissivity and Reflectance of common materials (Florida Solar Energy Center)

2.5 Thermal performance of Building

According to Badea (2014), the assessment of thermal performance of a building refers to "the process of modelling the energy transfer between a building and its surroundings" There are two types of building regarding the thermal performance:

- Conditioned building: the thermal performance means estimating the heating and cooling loads, so that sizing and selection of HVAC equipment can be properly made.

- Non-conditioned building: the thermal performance means calculating temperature variation inside the building over a specified time, and helps one estimate the comfort conditions.

To this point, a knowledge of the methods used to estimate buildings' performance is essential and enables the determination of the effectiveness of their design to achieve energy efficient buildings with comfortable indoor conditions (Nayak and Prajapati, 2006).

The heat exchange usually occurs in the form of conduction, convection, radiation, and ventilation (including infiltrations), either between a building and the external environment, or between a human body and the indoor environment. These processes affect either directly or indirectly the level of thermal comfort of users.

In addition to the heat gained by the internal space from surrounding walls, roof, ceiling, and floor, it is of great importance to know that part of heat is added to the indoor space, which certainly affects the level of thermal comfort due metabolic activities, equipment, and lighting. The ventilation not only affects the energy balance but also body comfort through the rate of convection and perspiration. The body either feels cool or hot based on loss and gain of heat respectively (Nayak and Prajapati, 2006).

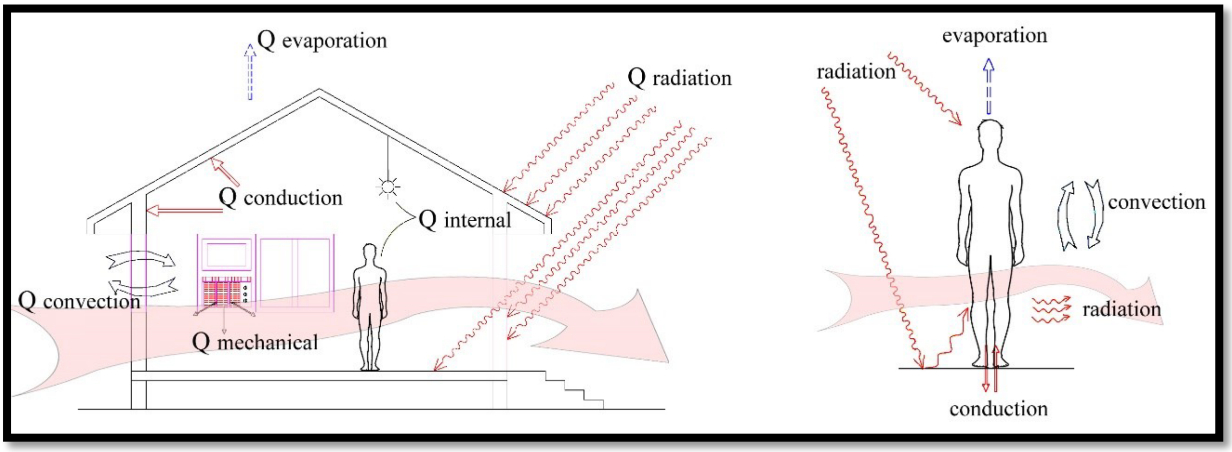


Figure 9: Heat Exchange Processes between building/human body and surrounding environment

2.5.1 Factors Affecting Thermal Performance of a Building

The thermal performance of a building depends on a large number of factors. Many studies have summarized the ones affecting the most the thermal performance of a building, which can be summarized as in table 2.

Table 3: Factors affecting the thermal performance of buildings

Factors	Description
Design Variables	Geometrical dimensions of building elements such as walls, roof and windows, orientation, shading devices, etc.
Material Properties	Density, specific heat, thermal conductivity, transmissivity, etc.
Climate data	Solar radiation, ambient temperature, wind speed, humidity, etc.
Building Usage	Internal gains due to occupants, lighting and equipment, air exchanges, etc.

2.5.2 Building Energy Demand

The energy demand of a building in an urban area does not only depend on the characteristics of the building itself but mainly on the surrounding environment. UHI effects at meso-and micro-scale as well as interactions with the surrounding buildings at neighbourhood scales do have an important effect on the energy demand of a building in an urban area (Rasheed, 2009). As compared to an isolated building, a building in an urban area experiences a number of effects resulted by the microclimate, such as:

(i) increased maximum air temperatures due to the urban heat island effect;
(ii) lower wind speeds due to a wind-sheltering effect;
(iii) reduced energy losses during the night due to reduced sky view factors;
(iv) altered solar heat gains due to shadowing and reflections;
(v) a modified radiation balance due to the interaction with neighbouring buildings.

All these effects have a significant impact on the energy demand of buildings (Kolokotroni., et al., 2008) because it affects the conductive heat transport through the building envelope, the energy exchange by means of ventilation (Ghiaus et al., 2006), and the potential to employ passive cooling (Geros et al., 2005) and renewable energy resources.

2.6 Thermal Comfort

The evaluation of the impact of microclimate on the building energy demand needs a detailed understanding of the thermal comfort. According to ISO 7730 (1994) and ASHRAE standards 55-66 (American Society of Heating, Engineers, and Institute, 2010; Esther and Sagada, 2014), thermal comfort is "the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation". Maintaining this level of thermal comfort is one of the outstanding objectives of architects and design engineers which make them face many challenges to utilize all the possibilities available to achieve it. Achieving a perfect state of comfort by one set of conditions for all occupants is impossible. This is due to the large number and diversity of factors that control thermal comfort such as age, sex, clothing, and level of activity of each person (Driver et al., 2012).

Thermal comfort is affected by independent environmental variables and independent personal variables (ASHRAE Handbook, 2001). The literature has identified the environmental factors that affect both person's thermal balance and thermal comfort:

- The dry bulb temperature, the humidity, and the relative velocity of the surrounding air,
- The temperature of any surfaces that can directly view any part of the body and thus exchange radiation (Levin, 1995).

While the personal factors are expressed by activity level, clothing, metabolic heat, state of health, acclimatization, expectations, and even access to food and drink (Ubbelohde et al., 2003; Chen et al., 2003).

According to Esther and Sagada (2014), the commonly used indicator of thermal comfort is air temperature because it is the easiest to use and people can rate it without any difficulty.

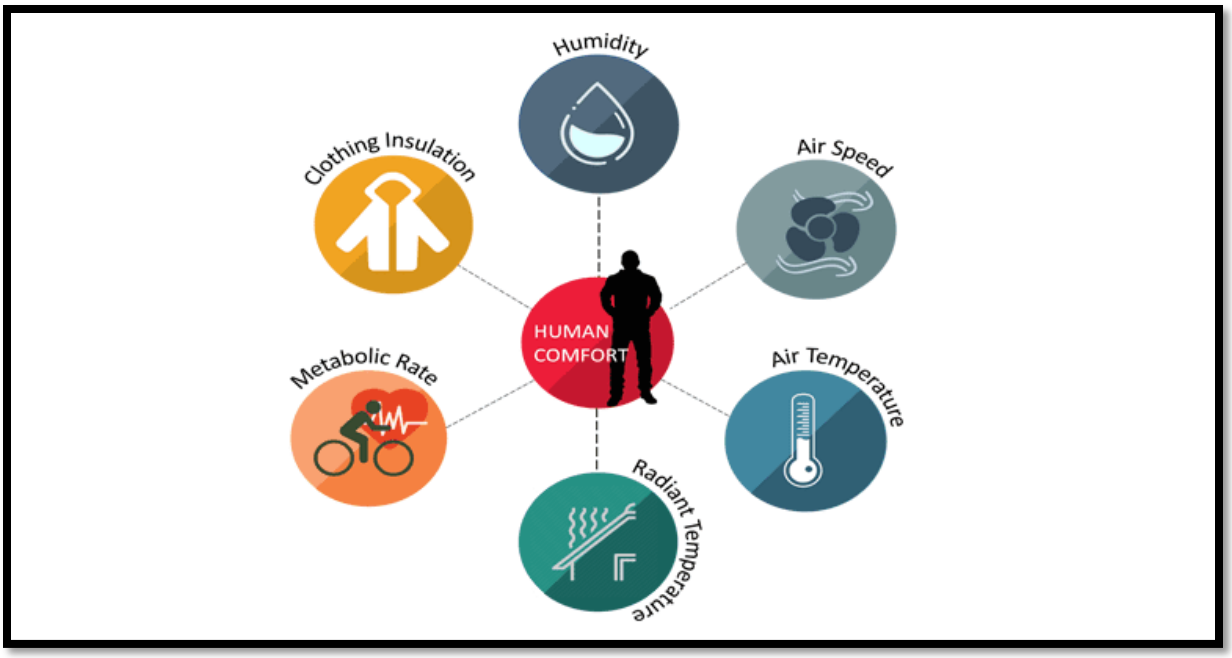


Figure 10: Factors affecting thermal comfort

There are two commonly used indicators to define the thermal comfort, the predictive mean vote (PMV) and predicted percentage of dissatisfied (PPD). Within the PMV index, +3 translates as too hot, while -3 translates as too cold, as depicted below.

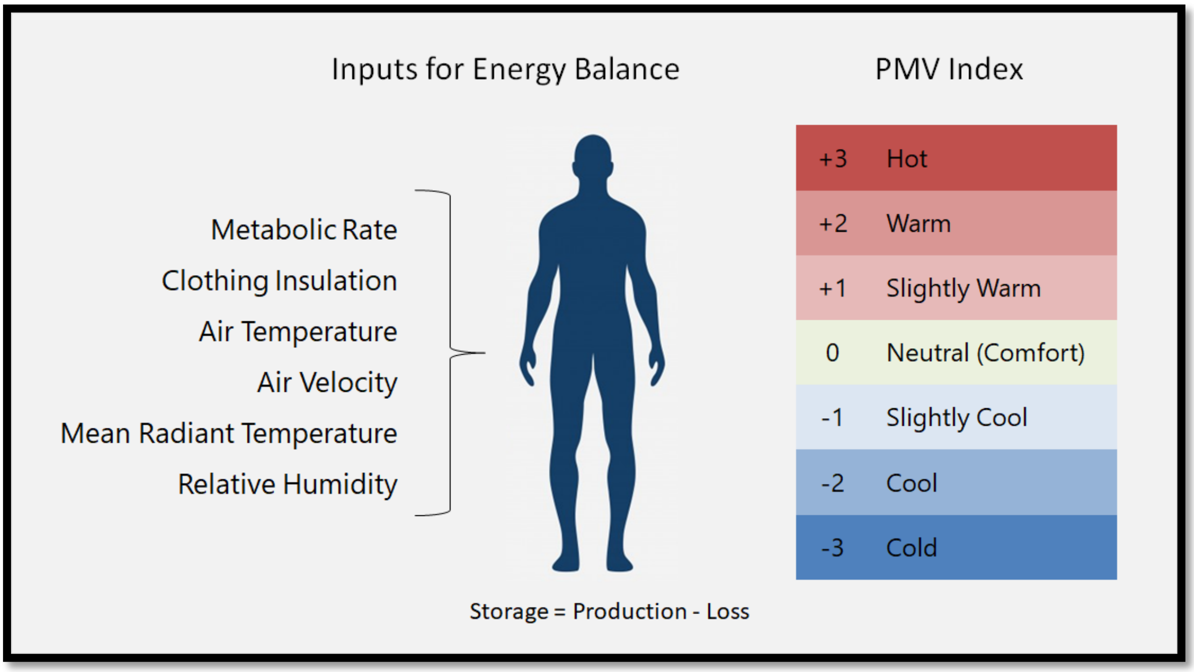


Figure 11: ASHRAE thermal sensation scale (Krarti, 2016)

In support of PMV, PPD (predicted percentage of dissatisfied) gives the percentage of people experiencing local discomfort.

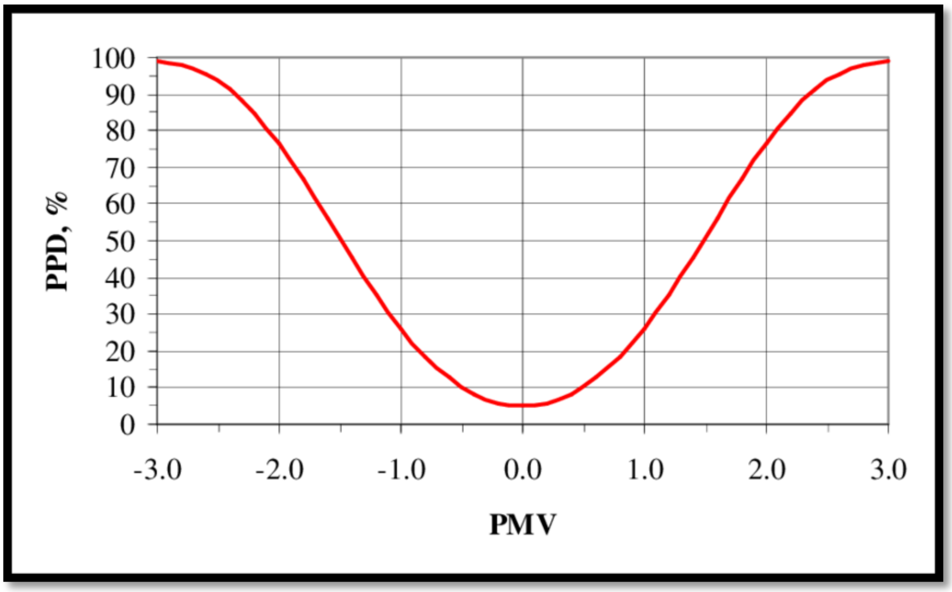


Figure 12: Thermal Comfort Indicators (Markov, 2002)

3. SITE ANALYSIS

3.1 Site Selection

NTNU Gløshaugen Campus in Trondheim, Norway is opted for the study. It is located on a plateau, approximately two kilometers south-east of city center. The campus comprises of about thirty buildings involved in research and education. Most of the university's science, engineering and architectural buildings are located at Gløshaugen Campus, whereas other faculties are spread over other campus. Apart from buildings, the campus has a fair distribution of internal roads, pavements, squares, lawns, gardens, and parking spaces. Therefore, this campus is an ideal location to evaluate the impact of microclimatic parameters on building energy demand on a non-residential building surrounded by functionally homogeneous buildings.

The present study comes in the light of the NTNU Campus Development Project which aims to expand the vision of zero energy building "to a campus perspective, which means that all activity on and adjacent to the campus will be at a net zero energy level in 2060" (The Vision Report for NTNU, 2014).

Figure 13: Location of the study area of NTNU campus within Trondheim, Norway (Picture source from Norwegian Mapping Authority www.kartverket.no)

Figure 14: NTNU Gløshaugen Campus area (Picture source from Norwegian Mapping Authority www.kartverket.no)

3.2 Climate

According to Köppen- Geiger climate classification, Trondheim falls under Warm-Summer Humid Continental Climate (Dfb). Interesting, before 1990, Trondheim was under Continental Subarctic Climate (Dfc). This type of climate is dominated by the winter season, a long and cold period with short and clear days. The summer is warm. Mean monthly temperatures are below freezing for three months. Snow remains on the ground for few months. Summer is short and mild, with long days and prevalence of frontal precipitation.

The average temperature for the year in Trondheim is 4.8˚C. The warmest month on average is July with an average temperature of 13˚C. The coolest month on average is January with an average temperature of -3˚C. The highest recorded temperature in Trondheim is 31.1˚C while the lowest recorded temperature is -26.1˚C. The average amount of precipitation for the year in Trondheim is 856mm.

The table below (table 4) presents a collection of key climatic data averaged over different periods.

Table 4: Climate information of Trondheim (www.seklima.met.no)

Climate Data	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Monthly temperature 1961-1990	-3.0	-2.5	0.0	3.0	9.0	12.0	13.0	12.5	9.0	5.5	0.5	-2.0
Monthly temperature 1991-2020	-1.0	-1.1	0.8	4.7	8.7	12.0	14.6	14.1	10.5	5.7	1.7	-0.7
Average windspeed 1996-2020	3.1	2.8	2.6	2.6	2.6	2.4	2.2	2.1	2.4	2.6	2.8	2.9
Relative humidity 2009-2020	74.1	73.7	71.0	70.8	67.6	73.2	74.5	76.4	78.2	78.0	77.2	78.0

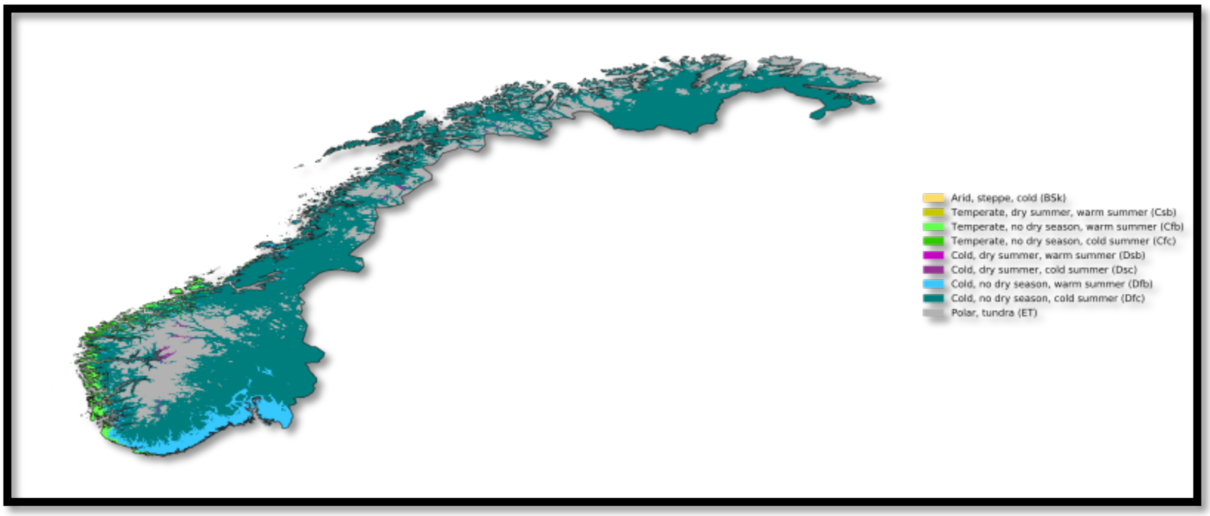


Figure 15: Köppen-Geiger Climate Classification Map for Norway: 1980-2016 (Beck et al., 2018).

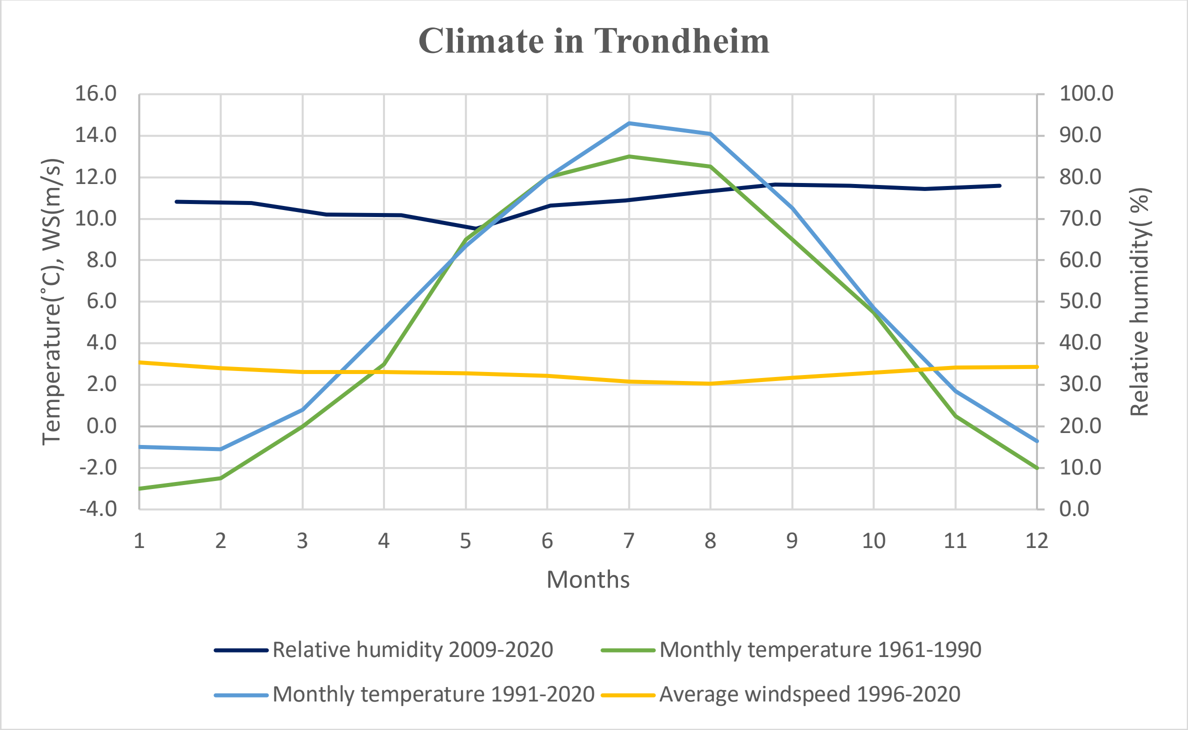
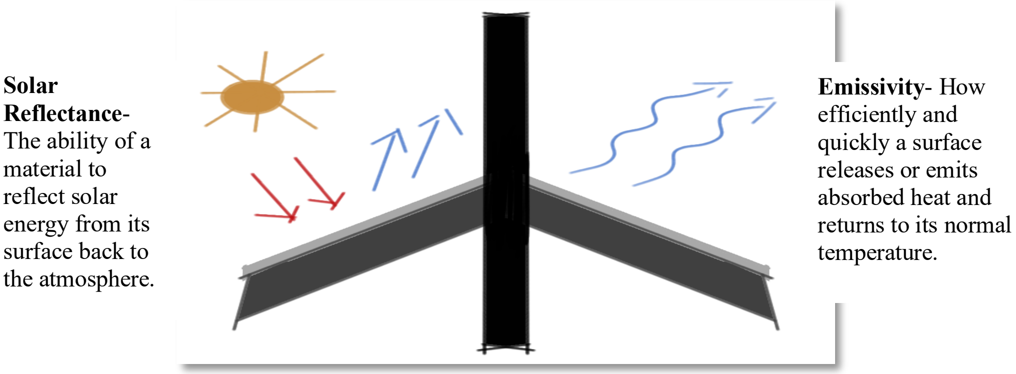


Figure 16: Representation of different climatic data in Trondheim recorded at Voll station.

As in figure 16, the temperature in Trondheim has been increasing at an alarming rate. The annual average between 1961 and 1990 was 4.8˚C but the annual average temperature between 1991 and 2020 is 5.8˚C, which is an increase by 1˚C. The humidity and wind speed remain relatively constant throughout the year with minor fluctuations.

3.3 Surrounding Materials

Microclimate is dependent on the properties of the surface materials in a neighbourhood. The property different materials are responsible for the amount of solar radiation being reflected, absorbed, or transmitted.



Solar Reflectance- The ability of a material to reflect solar energy from its surface back to the atmosphere.

Emissivity- How efficiently and quickly a surface releases or emits absorbed heat and returns to its normal temperature.

Figure 17: Difference between reflectance and emissivity

It is important to understand first how the surface material responds to the solar radiation and sunlight in order to understand the impact of microclimate on a building. The solar reflectance, also known as albedo effect, is the ability of material to reflect sunlight from its surface back into the atmosphere. Lower the albedo, more radiation from the sun is absorbed by the surface, thereby increasing the surface temperature.

The other important property is the emissivity of the material. It defines how efficiently and quickly a surface releases or emits absorbed heat via long wave radiation and returns to its normal temperature. High emissivity means that the surface releases high amount of thermal energy, thereby increasing the local temperature.

The following table (table 4) presents the albedo and emissivity value for each material at NTNU Gløshaugen campus. For both properties, the value ranges from 0 to 1.

Table 5: Albedo and emissivity of materials used in the study site (Sailor et al., 2010).

Location	Material	Albedo	Emissivity
Central Building Complex	Light painted concrete	0.5 - 0.95	0.95
Surrounding Buildings	Dark painted concrete	0.1 - 0.4	0.95
Ground	Asphalt	0.05 - 0.2	0.90 - 0.98
Ground	Pavement	0.1 - 0.4	0.90 - 0.95
Ground	Grass	0.2 - 0.3	0.97 - 0.98

3.4 Representative Building Selection

Since the aim of this study is to evaluate the impact of microclimatic parameters on the energy demand of a building, it is apparent that a representative building needs to be selected in the campus. The buildings at NTNU Gløshaugen campus are built over different periods of time starting from late 1950s. Most of the buildings were constructed before 1980s. The following figure (figure 18) shows the number of buildings built over different period.

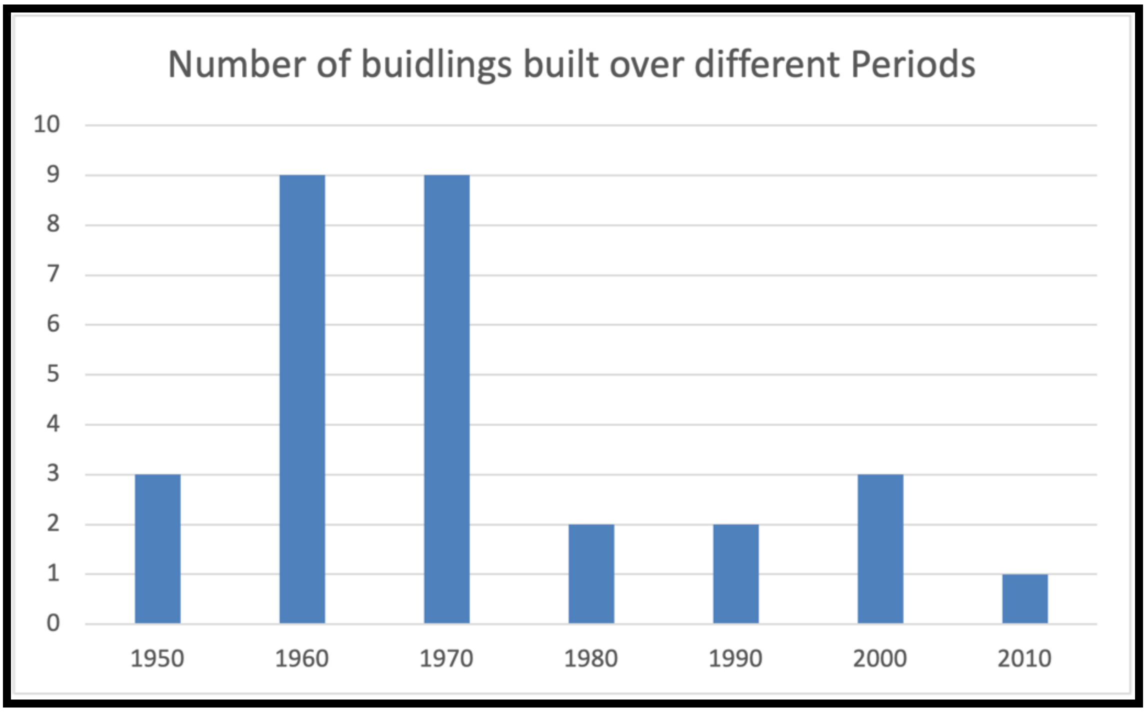


Figure 18: Frequency of building construction over different periods of time.

From figure 18, it is clear that most buildings were constructed in the 1960s and 1970s. Therefore, selecting a building from this period in this study can be regarded as most representative for NTNU campus. The other criteria considered for the selection of the representative building is the construction material. Most of the buildings built over these periods are built using concrete gable walls as load bearing structures.

Taking into considerations the year of construction and the material composition, the Central Building 1 (Sentralbygg 1) is selected for the study. It is a 13 storied office building, built in the year 1963. The building is a part of the central building complex as one of the two high rises that is connected by low rises along the central axis North-South.

The prominent position on the campus plateau and proximity to the center makes Sentralbygg 1 and the adjacent counterpart easily visible around the city and surrounding hills. The outside appearance is characterized by a dominant load-bearing structure and use of few materials which resemble the materials used in other surrounding buildings as well. The height of the building gives an additional advantage over the use of results obtained to predict the impact of microclimate on other surrounding buildings because all other buildings are lower in height than the selected building.

Figure 19: The case study building (shaded blue). Picture source: Google Map

The structural system of the Sentralbygg 1 has a skeleton type of load-bearing structure with columns projected outside the thermal barrier. The east and west façade are composed of solid gable walls with no openings. The North and south façade have columns and windows. To distribute loads, gable walls are solid concrete. Further, the two staircase cores are designed in a way to take up part of the load as well. In addition to the columns in the facade, a central supportive structure runs perpendicular to the gable walls.

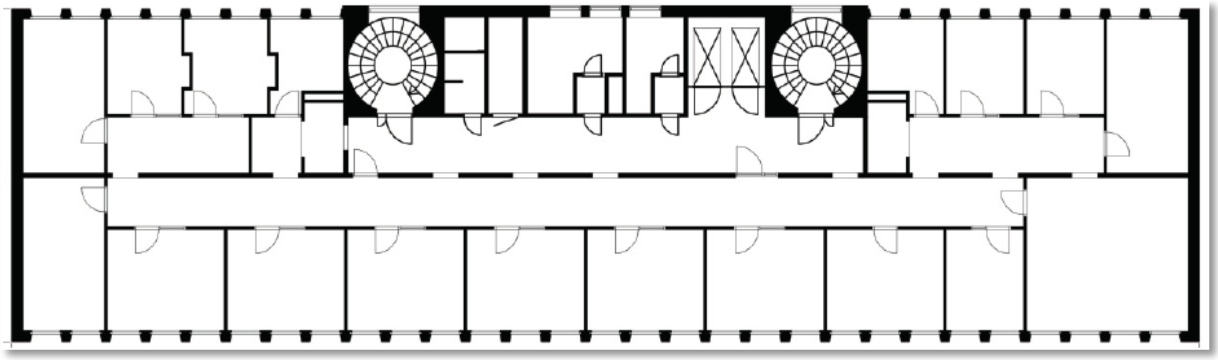


Figure 20: Typical floor plan

The main building facades have site cast columns that support the floor decks accented by prefabricated concrete panels with sub sills. Wall panels are insulated by 100 mm rockwool covered by wood panelling and gypsum board to the interior. Towards the interior, columns are insulated with 30 mm cork. The east and west gable walls are also in direct connection to the floor decks due to the homogenous single layer concrete structure. The solid gable walls have no openings and relies on the insulating properties of aerated concrete blocks (*siporex*) to the inside. On the south façade, windows have been renewed within the last few years. The new windows are 2 layered argon glass with LE coating (OptithermSN4). An additional glass pane protects the external blinds.

4. BUILDING MODELLING AND SIMULATION

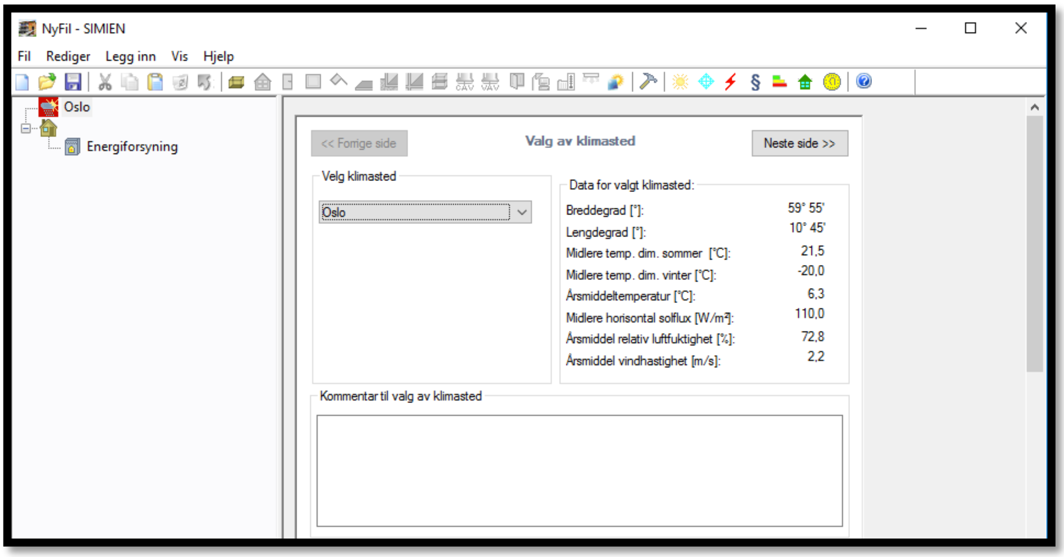
4.1 Building Energy Performance Simulation (BEPS) Tools

The Research Center on Zero Emission Neighbourhood and Smart Cities (ZEN) has performed a survey on different simulation tools used in SINTEF and NTNU. SIMIEN and IDA ICE come out to be the most used simulation tools to model the building energy demand (Djuric, et al., 2010).

4.1.1 SIMIEN

Simien is developed by *Programbyggerne ANS* and is a simulation program for calculating energy use, power demands and indoor climate in buildings. Simien uses dynamic simulations with 15-minute time steps and can be used for designing buildings with several thermal zones. Simien is one of the most used energy simulation programs in Norway because it is well adapted to Norwegian conditions in terms of climate data, standards, and checks against Norwegian regulations. In addition to this, the program has a user-friendly interface, which makes it easy to use. (Djuric et al., 2010).

However, the simulation model in Simien isn't created with shapes or geometry. The different zones are connected to each other by a determination of the shared floor, ceiling or wall area. In addition to this, the placing of doors, radiators etc. can't be placed exactly on where it is supposed to be in reality. The program is therefore unsuitable for simulations of buildings, where the shapes and placing of elements are important for the temperature distribution. Since Simien is not geometry based, the model can't be visualized in 3D.



Valg av klimasted

Velg klimasted: Oslo

Data for valgt klimasted:

Breddegrad [°]:	59° 55'
Lengdegrad [°]:	10° 45'
Midlere temp. dim. sommer [°C]:	21,5
Midlere temp. dim. vinter [°C]:	-20,0
Årsmiddeltemperatur [°C]:	6,3
Midlere horisontal solflux [W/m²]:	110,0
Årsmiddel relativ luftfuktighet [%]:	72,8
Årsmiddel vindhastighet [m/s]:	2,2

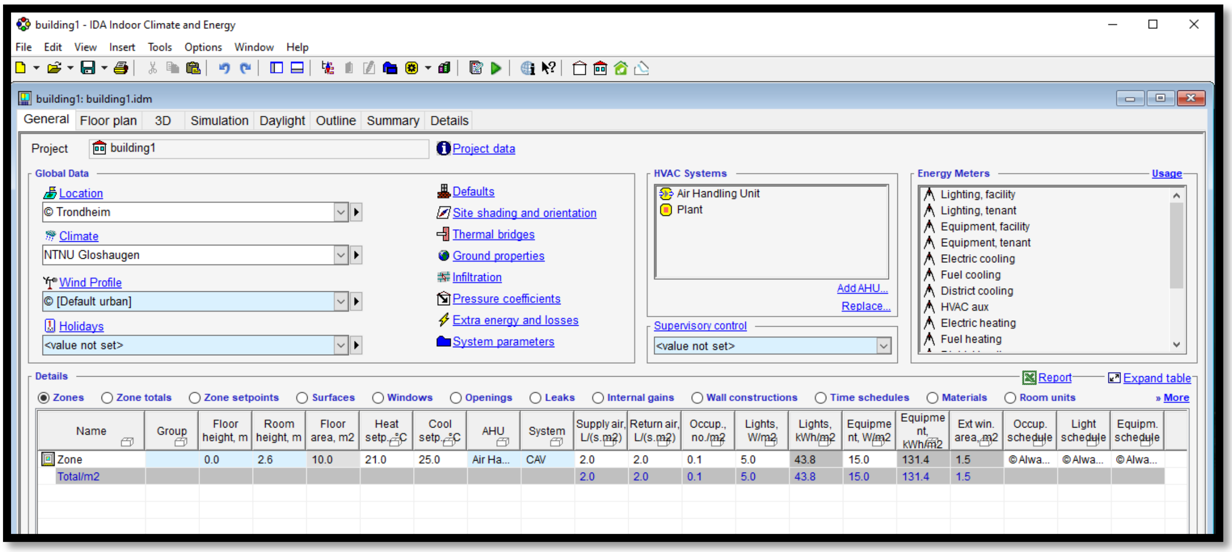
Kommentar til valg av klimasted

Figure 21: SIMIEN Interface

4.1.2 IDA ICE

IDA Indoor Climate and Energy (IDA ICE) is a dynamic multi-zone simulation program, which can be used for examining the thermal indoor climate and energy consumptions in buildings. IDA ICE is developed by EQUA simulations AB (Equa Simulation AB, 2014).

IDA ICE requires that a large number of values must be added to the model. Despite this, the program provides a good overview of the model with the help of tables for selected values and 3D visualization. A simulation model in IDA ICE is created by drawing in 2D. The shapes of the rooms/zones are determined by the user which enables modelling of complex shapes and geometry. The simulation model can be created to be exactly like the actual building. Doors, radiators, windows etc. can be placed exactly where they are. The accuracy of the simulation model is crucial when the temperature distribution in some zones is dependent on the air flow through open doors. The higher accuracy in IDA ICE makes it more suitable for evaluation of the thermal indoor climate in complex simulation models than with Simien.



Project: building1

Location: © Trondheim

Climate: NTNU Gloshaugen

Wind Profile: © [Default urban]

Holidays: <value not set>

Supervisory control: <value not set>

Name	Group	Floor height, m	Room height, m	Floor area, m2	Heat setp., °C	Cool setp., °C	AHU	System	Supply air, L/(s.m2)	Return air, L/(s.m2)	Occup., no./m2	Lights, W/m2	Lights, kWh/m2	Equipment, W/m2	Equipment, kWh/m2	Ext win. area, m2	Occup. schedule	Light schedule	Equipm. schedule
Zone		0.0	2.6	10.0	21.0	25.0	Air Ha...	CAV	2.0	2.0	0.1	5.0	43.8	15.0	131.4	1.5	©Alwa...	©Alwa...	©Alwa...
Total/m2									2.0	2.0	0.1	5.0	43.8	15.0	131.4	1.5			

Figure 22: IDA ICE Interface

Therefore, based on the flexibility, accuracy and user-friendly interface of the program, IDA ICE is selected for the modelling and simulations of the building energy demand in this study.

4.2 Input Parameters

4.2.1 Climate Data

The climate information is the most important input data required to run the simulations. In order to evaluate the impact of microclimate on the energy demand of the building, the climate data is collected from weather stations and also generated through computational fluid dynamics (CFD) at building surface level. The main climatic data required are air temperature, relative humidity, wind speed, wind direction and solar radiation. Each of these data is collected from three different locations based on the proximity to the study building.

At the meso scale, the main weather station is located at Værnes Airport which is about 26 kilometers away from the study site. This is the Typical Meteorological Year (TMY) data used for the building designs normally. At micro scale, the weather data is collected from one of the weather stations at NTNU Gløshaugen campus. This data forms the basis for more accurate climatic information which is the product of the influence of different physical properties such as landscapes, geometry, materials, vegetations, layout of buildings etc. in the campus. Going further, the CFD generated weather data are collected at different levels and faces of the representative building which forms the basis of most detailed climate information at microscale level. These three scales of climate data collections are presented in figure 23.

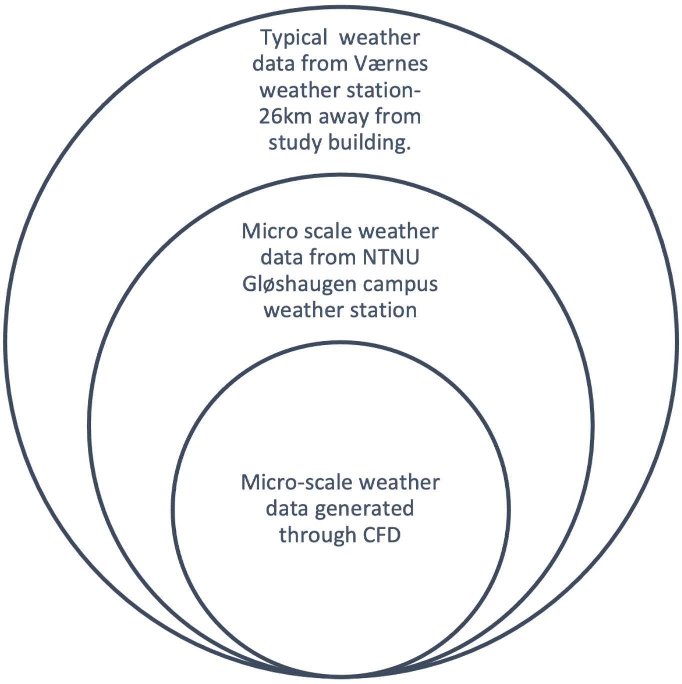


Figure 23: Different scales of input climatic data based on the proximity to the study building.

4.2.2 Building Geometry

IDA ICE is a geometric based simulation program which requires the users to model the building as accurate as possible. Therefore, the geometric information of the building is an important input parameter. The modelled building is a 13 storied office building with dimensions of 41m x 11m externally, floor to floor height of 3m and the window size of 1m x 1.77m. The key dimensions are presented in the table below.

4.2.3 Building Properties

The energy balance in the building is a function of different properties and characteristics of different components of the building. The heat exchange between the indoor and outdoor of the building happens through conduction, convection, infiltration, evaporation and radiations. These are the properties of the materials and layout of the building. The u-value of the envelope, specific heat capacity of different materials, infiltration rate and thermal bridge values are the important input parameters to simulate the energy demand of the building. These values are presented in the table below.

4.2.4 Technical Installations

The technical installations are mainly the ventilation system in the building. The building has a balanced ventilation system with a rotary heat recovery system. The air handling unit is located in the 6th floor. Since there is no extended ceiling, ventilation ducts are exposed and possibly narrower than in the case of a new building. Heat recovery of 70 % momentary temperature efficiency was found from the SD-system.

For the state of analysis, information about the existing building was acquired by consulting construction details, inspection and operational records. Energy calculations and definition of transmission losses follow the Norwegian method NS-3031:2010. Material properties are in conjunction to NS-EN ISO 10456:2007.

The summary of the key input parameters are presented in the table below.

Table 6: Key input parameters

Elements	Values	Descriptions	Source
Heated Floor Area (m^2)	5855	41m x 11m wall to wall dimensions	Building geometry
Heated Volume (m^3)	16528	13 storied high building with 3m floor height on each floor	Building geometry
Normalized Thermal Bridge (Wm^2/K)	0.08	Continuous concrete gable wall on east and west facades	Energy Certificate
Air Leakage Rate (n50) (1/h)	1.5	Requirement based on Norwegian standards before 2017	Norwegian Standard
Specific Fan Power: SPF ($kW/m^3/s$)	1.5	Requirement based on Norwegian standards	NS 3031
U-value: Façade (W/m^2K)	0.75	East and West facades have concrete walls with siporex blocks placed internally, north and couth facades have concrete columns with 10cmm cork insulation placed at the internal side, other parts have concrete wall with 30cmm mineral wool placed at the internal part.	Drawing records and energy certificate

U-value: Windows (W/m^2K)	2.23	2 layered argon glass with LE coating (OptithermSN4). An additional glass pane protects the external blinds.	Drawing records, construction details, manufacture information.
U-value: roof (W/m^2K)	0.30	Concrete roof with mineral rigid insulation.	Drawing records
Internal Load: Light (W/m^2)	8	Internal load from lighting based on Norwegian standard requirements	NS 3031
Internal Load: Equipment (W/m^2)	11	Internal loads from equipment in an office building based on Norwegian standards	NS 3031
Internal Load: Occupants (W/m^2)	6	Internal loads from occupants based on Norwegian standards	NS 3031
Schedule	7am-7pm	07-19 during weekdays, half time in July	Ns 3031

Pressure Coefficients

Table 7: Input pressure coefficient values generated through CFD

Facade (Azimuth)	0° (North)	45° (Northeast)	90° (East)	135° (Southeast)	180° (South)	225° (Southwest)	270° (West)	315° (Northwest)
NE (64°)	-0.09	0.23	0.35	-0.09	-0.22	-0.18	-0.14	-0.16
SE (154°)	-0.21	-0.30	0.02	0.51	0.42	-0.09	-0.18	-0.11
SW (244°)	-0.28	-0.25	-0.23	-0.20	0.01	0.36	0.21	0.02
NW (334°)	0.14	-0.09	-0.31	-0.07	-0.12	-0.27	0.06	0.17
Roof (-)	-0.44	-0.39	-0.43	-0.40	-0.43	-0.37	-0.28	-0.24

The pressure coefficient values are collected from CFD analysis carried out by a PhD scholar. These input data are used for the simulations using CFD generated weather data. For the annual simulation using the recorded weather data from the stations, the data with the “auto fill” option is used in IDA ICE.

4.3 Zoning

The simplification of the model is necessary to optimize the simulation time . Therefore, zoning the space based on functions and orientations is carried out in IDA ICE to simplify the model. Considering the functional aspect of the building, each floor is divided into five different zones: south, east, west, corridor and core. The first three zones are offices facing different directions. The corridor is the passage space in between the offices for the movement of occupants and the core is the zone for different services facilitating the building (toilet, elevators and stairs). The ground floor and the first floor have different layout connected to the *stripa,* which is a long corridor connecting the central building complex.

Each zone is equipped with an ideal heating element that determines how much energy would be needed to keep the zones at setpoint temperature. The model has the windows placed on facades with a close resemblance to that of the actual layout in the representative building.

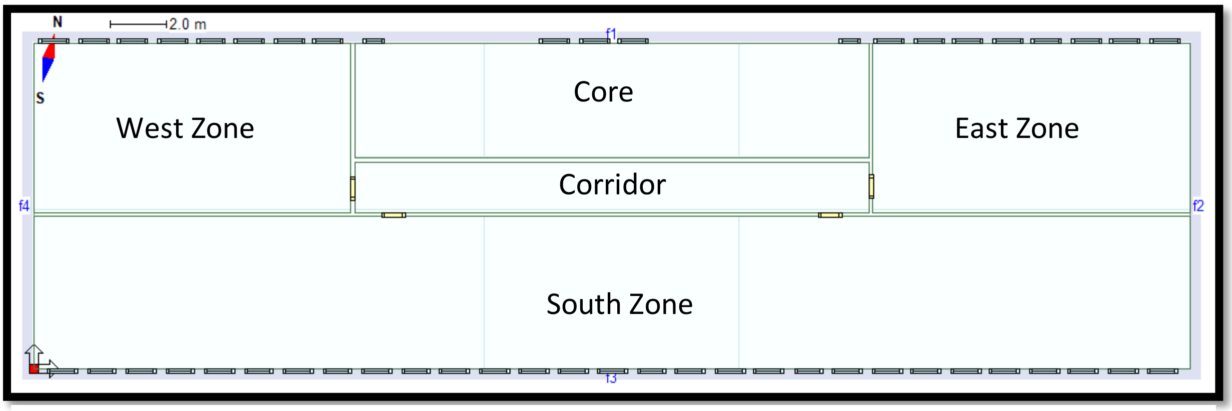


Figure 24: Zoning of the model in IDA ICE

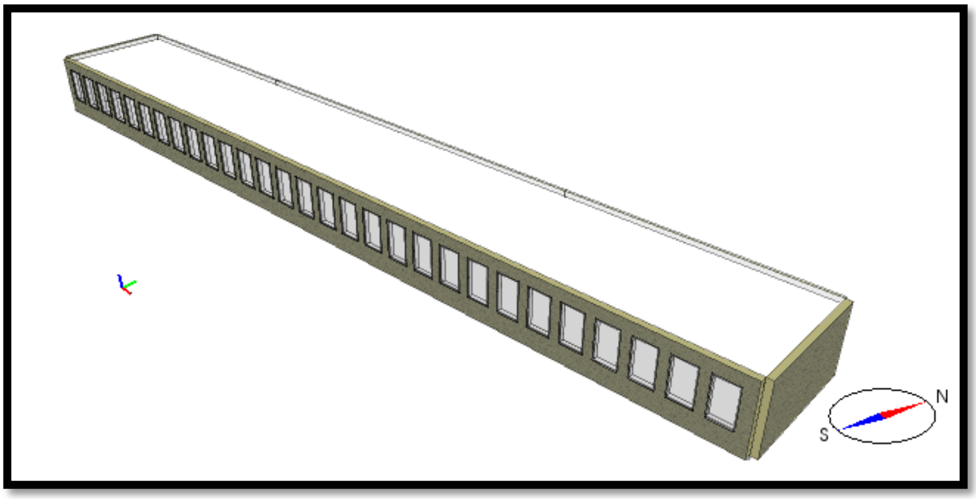


Figure 25: View of a zone in IDA ICE

4.4 Shadings

Since microclimate is a function of its surrounding, the shadings caused by the surrounding infrastructures need to be taken into considerations. The surrounding infrastructures block the access to solar radiations on the facades of the building, thus affecting the energy demand of the building. The surrounding infrastructures also influence the daylight distribution inside the building, but the daylight analysis of the building is not in the scope of this thesis. Therefore, to model the building in IDA ICE, the consideration of the shadings from the surrounding infrastructures is important. The figure below shows the placement of shading infrastructures within the influential range of the study building.

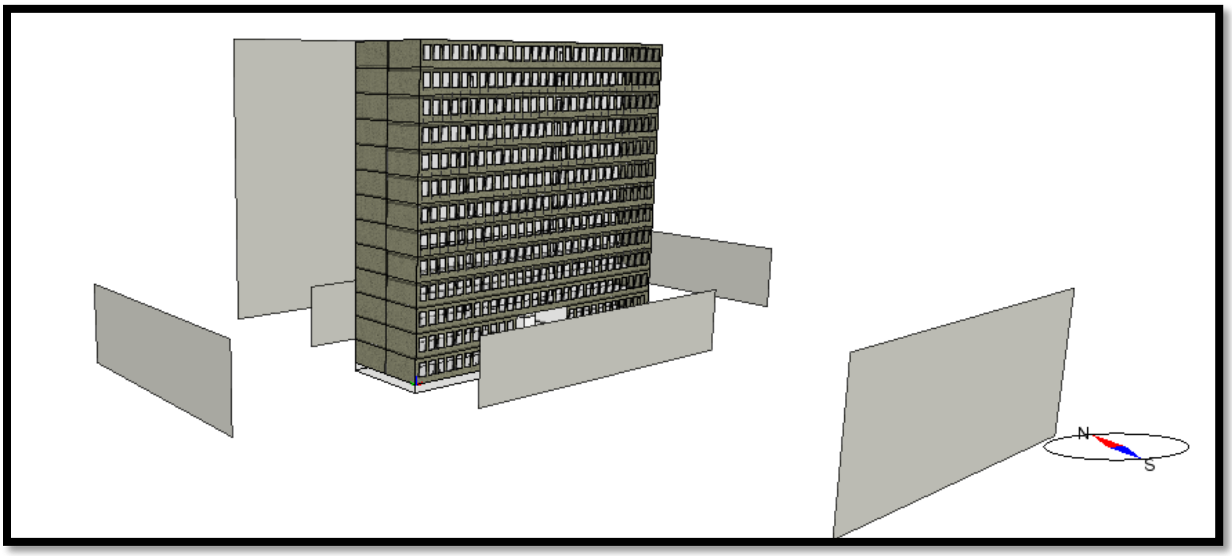


Figure 26: View of the model from the west

4.5 Simulations

The simulation of the modelled building is necessary to quantify the impact of the microclimate on building energy demand. With the necessary input data described above, the building is simulated to quantify the energy demand of the building. The variable input parameter is the climate. Following different climate files are considered for evaluation and comparison of the impact of microclimate on building energy demand:

1. Typical climate data from Værnes weather station- the annual climate data for the year 2020 is collected from Norwegian Center for Climate Service (www.seklima.met.no) and a *.prn* file created in Microsoft excel which is the input file accepted in IDA ICE.
2. Climate data from Gløshaugen weather station- the annual climate data for the year 2020 is collected from NTNU Gløshaugen weather station record and a *.prn* file is created in Microsoft excel.
3. Climate data from CFD- the microclimatic data are generated through CFD analysis of the representative building by a PhD scholar working at ZEN which are processed in Microsoft excel to create .prn file. These data are collected for two case-based scenarios:

a) Base case- the weather data generated for summer and autumn seasons with the surrounding environment kept as it is.
b) Without vegetation- the weather data generated for summer and autumn seasons with the removal of vegetations from the surrounding environment.

The modelled building is simulated for each of these climate file and the analysis and comparisons are performed based on the results obtained. The following performance indicators are used for the evaluations:

- Energy demand for heating, cooling, ventilation, light, equipment and other auxiliary systems.
- Temperature trends in zones and surfaces.

These are discussed in detail on next section “Results and Discussions”.

5. RESULTS AND DISCUSSIONS

5.1 Comparative Results of Climate

The comparative analysis mainly deals with the annual weather data from two stations, viz., Værnes and Gløshaugen. The former is the typical weather station for Trondheim and the latter is the local weather data associated with NTNU Gløshaugen campus. This analysis is to compare the difference in the weather data and how this influences the energy demand in the building. The main comparative indicators are air temperature, solar radiation, wind speed, humidity and heating degree days.

5.1.1 Air Temperature

The difference in average daily air temperature at two different stations are presented in the chart below (figure 27).

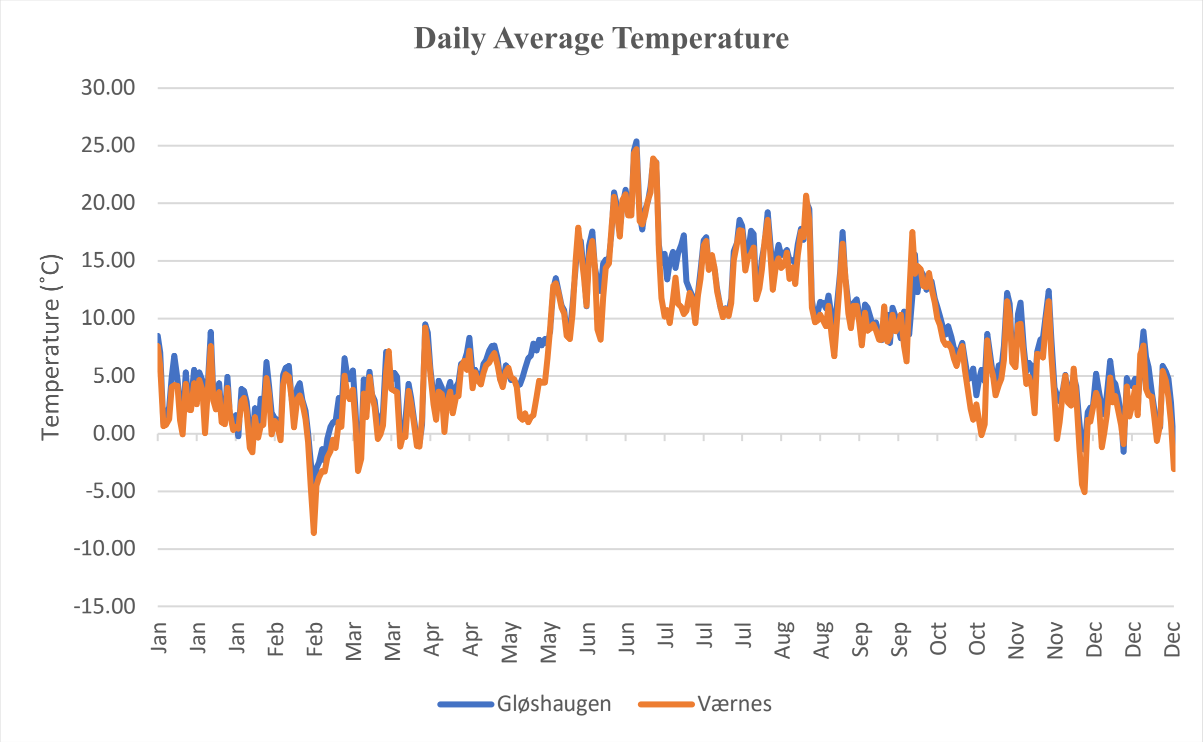


Figure 27: Comparative graph of daily average air temperatures between two stations for the year 2020.

It is evident that the fluctuations of temperatures within short period of time is higher in Værnes than in Gløshaugen. For instance, in the month of February, there is a larger difference of temperatures in consecutive days recorded at Værnes than that recorded at Gløshaugen. Similarly, in the month of May, Gløshaugen has recorded a gradual change in temperature, whereas the temperature recorded at Værnes is abruptly fluctuating over consecutive days. The maximum daily average temperature for both the station has no significant variations with Værnes having 25.5˚C and Gløshaugen having 25.3˚C both in the month of June. However, there is a larger difference in minimum temperatures. The lowest mean daily temperature recorded for Værnes is -8.6˚C, whereas, for Gløshaugen it is -5.0˚C, both in the month of February.

5.1.2 Maximum and Minimum Temperature

Table 8 shows the recorded maximum and minimum temperature (hourly averaged) in both the stations.

Table 8: Comparative maximum and minimum temperature recorded at two stations.

Station	Maximum Temperature (˚C)	Minimum Temperature (˚C)	Annual Average (˚C)
Gløshaugen	30.4	-8.9	8.1
Værnes	33.8	-13.3	6.2

The maximum temperatures were recorded in the month of June and minimum temperatures were recorded in the month of February for both the stations. It shows that Værnes station recorded higher maximum and minimum temperature compared to Gløshaugen station. For Værnes, the difference between maximum and minimum temperature is 47.1˚C, whereas the difference between maximum and minimum temperature recorded at Gløshaugen station is 39.2˚C. The annual average temperature for Værnes is 6.2˚C, whereas for Gløshaugen it is 8.1˚C, which is about 2˚C higher than Værnes.

Table 9: Comparative representation of total number of hours below freezing and above 25˚C between two stations for the year 2020.

Stations	Number of Hours	
	Below 0˚C	**Above 25˚C**
Gløshaugen	620	54
Værnes	738	86

Table 9 shows the total number of hours the recorded temperature was below 0˚C and above 25˚C for Gløshaugen and Værnes station. The Værnes station recorded a 19% higher number of hours below freezing (738 hours) as compared to that recorded at Gløshaugen station (620). Similarly, the recorded number of hours when the temperature went above 25˚C is higher in Værnes station (86) as compared to that of Gløshaugen station (54).

5.1.3 Heating Degree Days

A heating degree day (HDD) compares the mean (the average of the high and low) outdoor temperatures recorded for a location to a standard temperature, usually 17° Celsius (C) in Norway (Enova, 2017). HDD provides a simple metric for quantifying the amount of heating that buildings in a particular location need over a certain period (e.g. a particular month or a year). In conjunction with the average U-value for a building they provide a means of roughly estimating the amount of energy required to heat the building over that period.

The monthly heating degree days for Værnes and Gløshaugen stations are presented in figure 28.

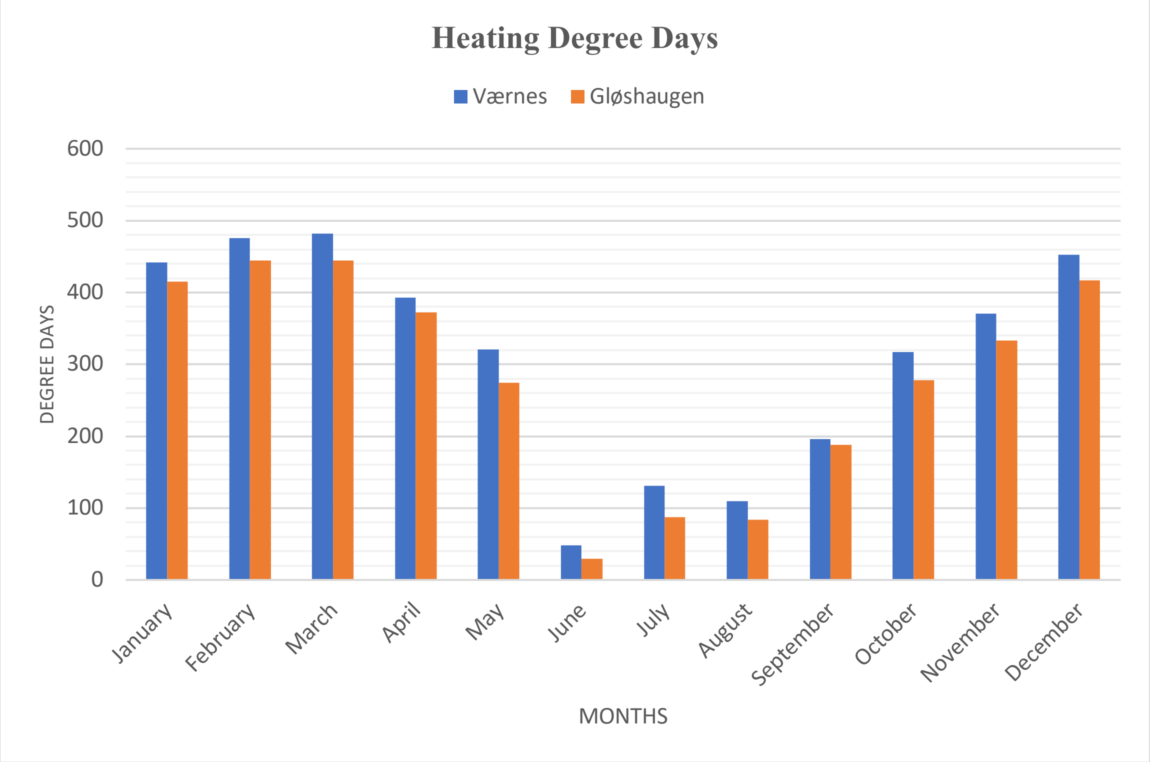


Figure 28: Comparative representation of monthly heating degree days between two stations.

The HDD associated with the climate data from Værnes weather station has higher values than that from Gløshaugen for every month. The months of December, January, February and March have maximum heating degree days, whereas June, July and August have minimum heating degree days with June having the lowest. The annual heating degree days for Værnes station is 3738.5, whereas for the Gløshaugen station it is 3368.4. The heating degree days associated with weather data from Værnes is higher by 11% as compared to the weather data associated with Gløshaugen for the year 2020.

5.1.4 Wind Velocity

The obstruction and friction from the urban landscape is one of the major factors affecting the wind velocity and direction. The chart below represents a comparison of daily average wind velocity recorded at Værnes and Gløshaugen weather station for the year 2020.

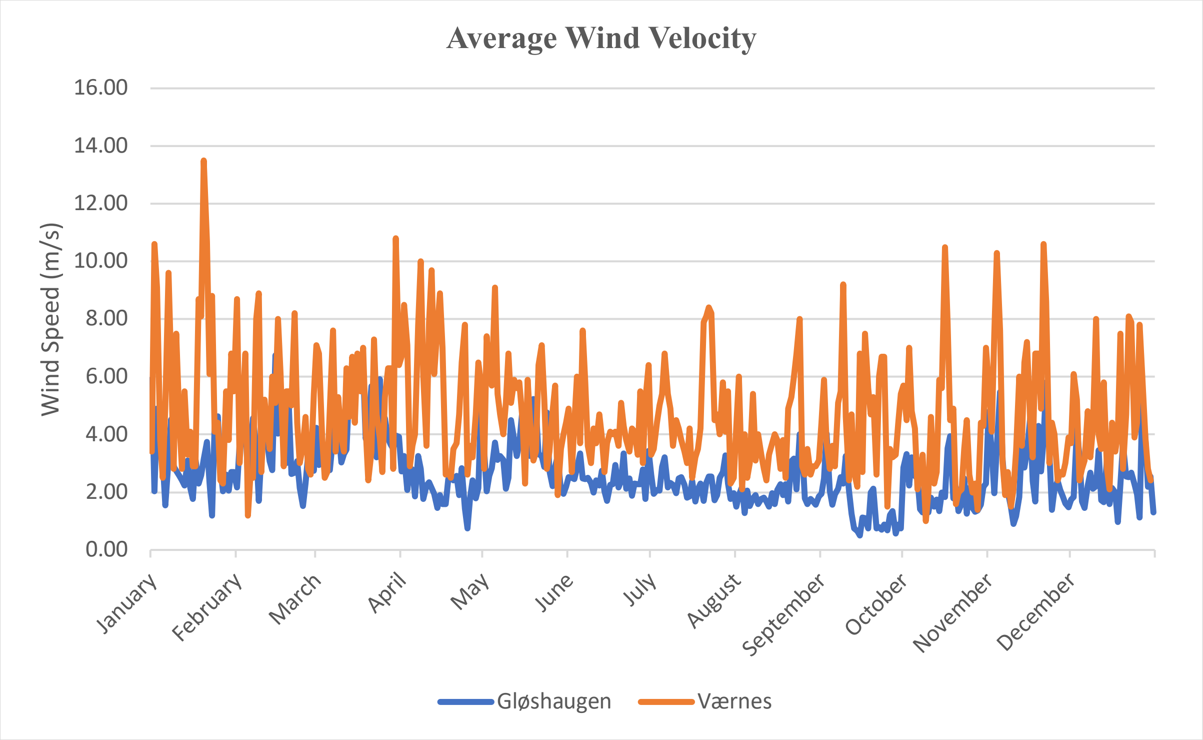


Figure 29: Comparative representation of wind velocity in two different stations for the year 2020.

There is a major difference in the wind velocity recorded at Værnes and Gløshaugen weather station. The velocity of wind is significantly higher in Værnes as compared to that in Gløshaugen. The Gløshaugen station recorded most of the days with wind speed below 4m/s and a significant number of days below 2m/s. On the other hand, Værnes station recorded most of the days with wind speed above 4m/s and a significant number of days above 8m/s. The highest wind velocity recorded at Gløshaugen station is 6m/s, whereas the maximum wind velocity recorded at Værnes is 13.5m/s which is more than twice that of Gløshaugen.

5.1.5 Discussions

The crow-flies distance between NTNU Gløshaugen campus and Værnes is about 26km. The weather data for Trondheim is typically associated with the weather station at Værnes, which means, most of the building energy design use the weather data recorded at Værnes. In addition to Værnes being at meso-scale radius of proximity from the study site, the urban composition is different. Værnes has the urban landscape designed for the airport with open space and low-rise buildings, surrounded by rural areas, whereas, Gløshaugen campus has a concentration of more than 30 buildings clustered together with fewer open spaces, surrounded by densely populated neighbourhood as shown in figure 30.

Figure 30: Urban landscape of Gløshaugen (left) and Værnes (right). Source: Google map.

As discussed in the theoretical part in section 2 of this thesis regarding the factors affecting microclimate, these differences in urban landscape between the two places create different microclimate.

This is further supported by the comparative results of air temperature as presented in figure 27 where the average annual air temperature recorded at Gløshaugen is 2˚C higher than that in Værnes.

Similarly, Værnes has 2 times higher wind speed as compared to Gløshaugen (Figure 29) due to fewer number of wind barriers associated with the airport landscape being one of the contributing factors. This is a perfect evidence to show that urban environment leads to lower wind speed.

The weather data used from the mesoscale radius of coverage for building energy designs have significant consequences in transforming into a zero-emission neighbourhood. Værnes station recorded a greater number of hours (738) when the temperature dropped below 0 as compared to that that recorded at Gløshaugen (620). Further, the heating degree days as presented in figure 28 shows that, the building designed in Gløshaugen using the weather data from Værnes has about 11% excess energy demand for heating, which can be avoided by simply taking the weather data from the Gløshaugen campus instead of that of Værnes. This is one of the ways of taking advantage of the microclimate. In colder climate as that in Trondheim, the data shows that microclimate can help reduce the heating demand if taken into considerations.

5.2 Microclimatic Data from CFD

CFD analysis data generated by a PhD scholar, was collected for 1 week each in summer (15th-21st June) and autumn (16th-22nd September). The data was collected for two scenarios, base case scenario and no-vegetation scenario. Base case scenario is the way the campus really is, including trees, grass, different surface materials like concrete, asphalt etc. In the no-vegetation scenario, trees are removed, and grass surface is substituted with concrete.

The average weather data (mean of south, north, east and west facades) at the height of 24m from the ground was extracted for creating a weather file. The data extracted were temperature, wind speed and wind direction. Solar radiation and humidity were taken from the recorded data from weather station at the campus.

5.2.1 Summer Case

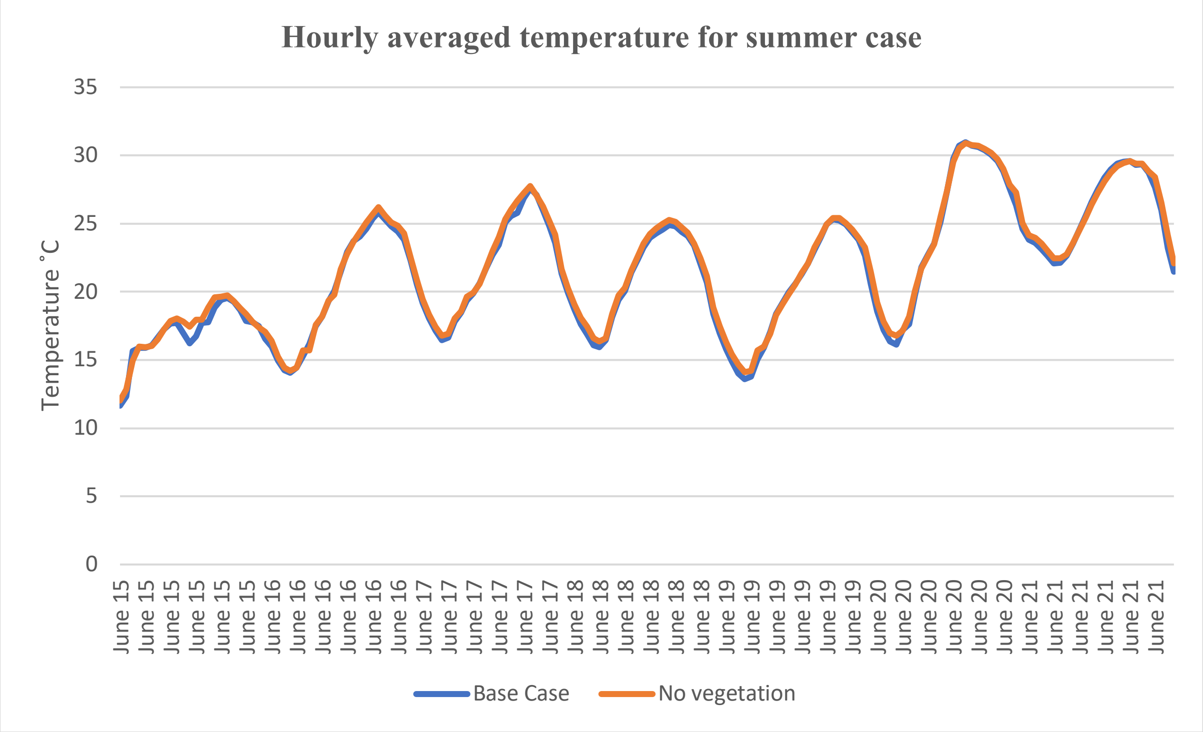


Figure 31: Comparative representation of hourly averaged temperature for two scenarios in summer 2020.

The average temperature for the week (June 15- June 21) for base case scenario is 21.5 ˚C and for no-vegetation scenario is 22.1˚C, which is higher by 0.6˚C. There is an increase of temperature by about 3% when the vegetation is removed from the surrounding.

One of the possible reason for this low difference could be that the point of study is far from the grass surface (24m above the ground). Therefore, its effect on the air temperature is smaller.

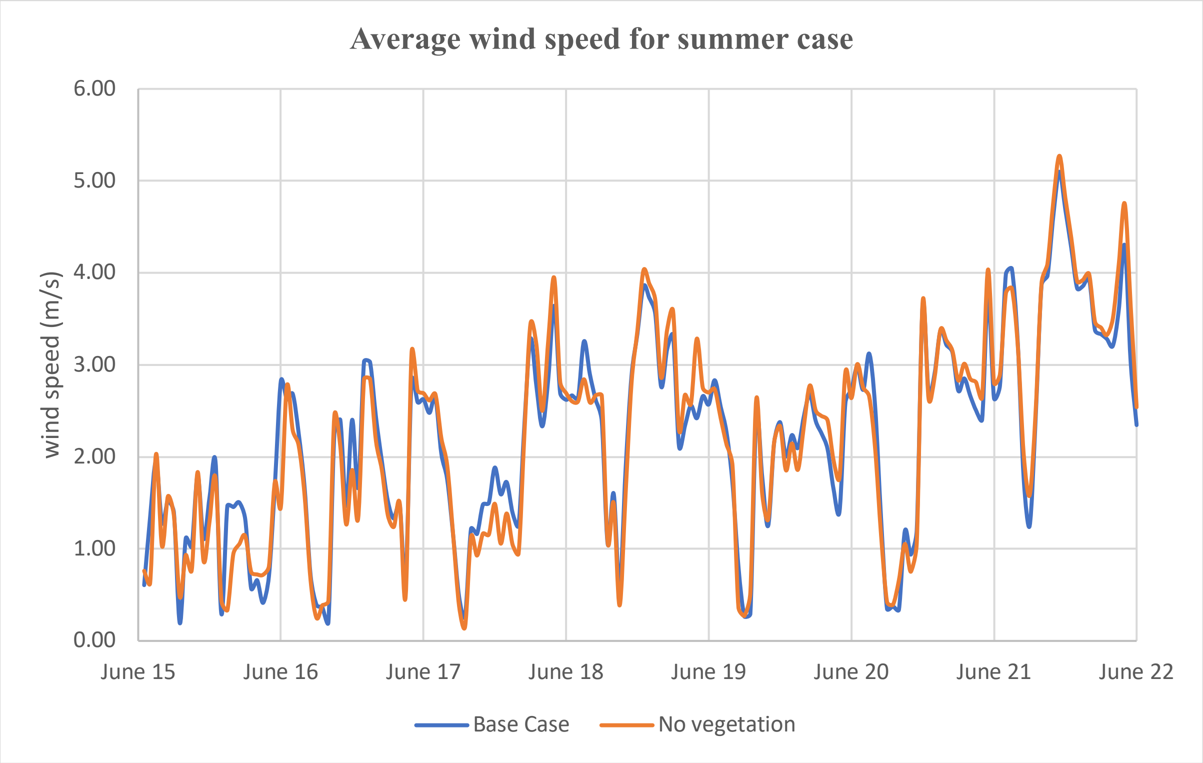


Figure 32: Comparative representation of hourly averaged wind speed for two scenarios in summer 2020.

The maximum wind speed for base case scenario is 5.0 m/s and the maximum wind speed for no-vegetation is 5.3m/s. Taking the average for both the scenarios, 2.0m/s for base case and 2.2m/s for no-vegetation scenario, it is 10% higher which is significant just for 6 days of observation period. This is one of the evidences to show that vegetations in an urban landscape lower the wind speed.

5.2.2 Autumn Case

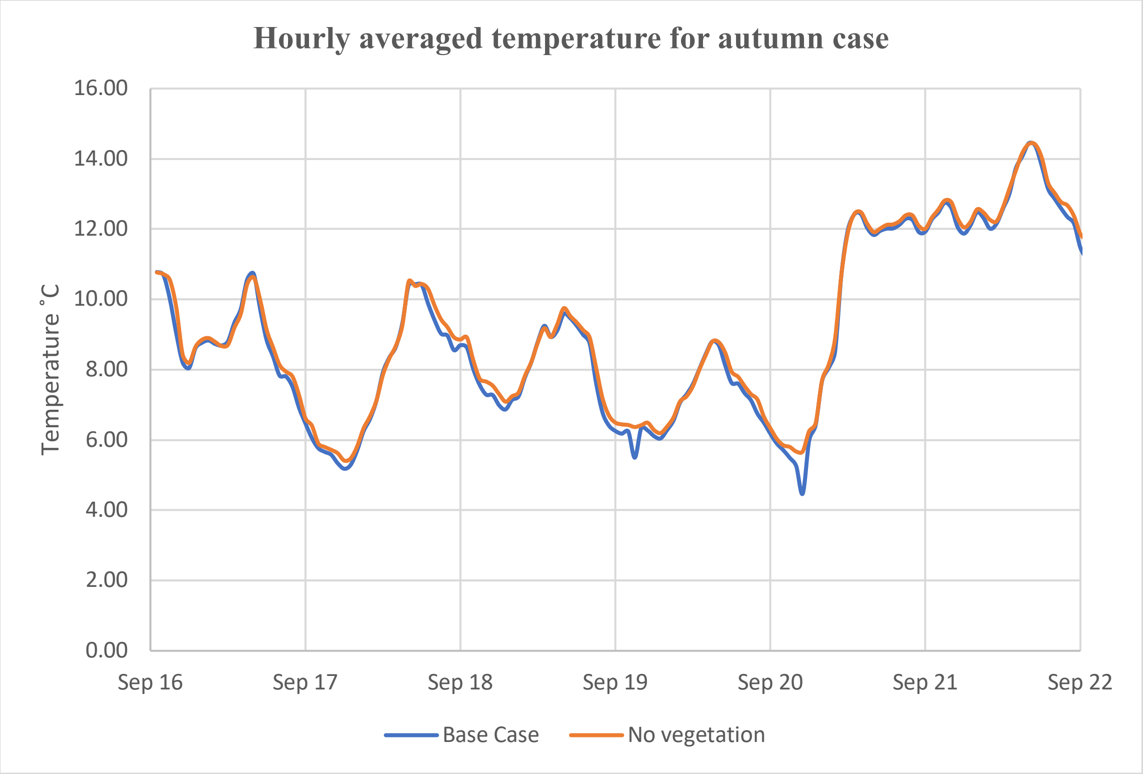


Figure 33: Comparative representation of hourly averaged temperature data for two scenarios in autumn 2020.

The one-week comparative data for hourly averaged temperature for the base case scenario and no-vegetation scenario shows that the temperature profile without vegetation is slightly dominant as compared to that of the base case. The average temperature over a week for base case scenario is 9.1˚C, whereas the average temperature for no-vegetation scenario is 9.5˚C, which is higher by about 4%.

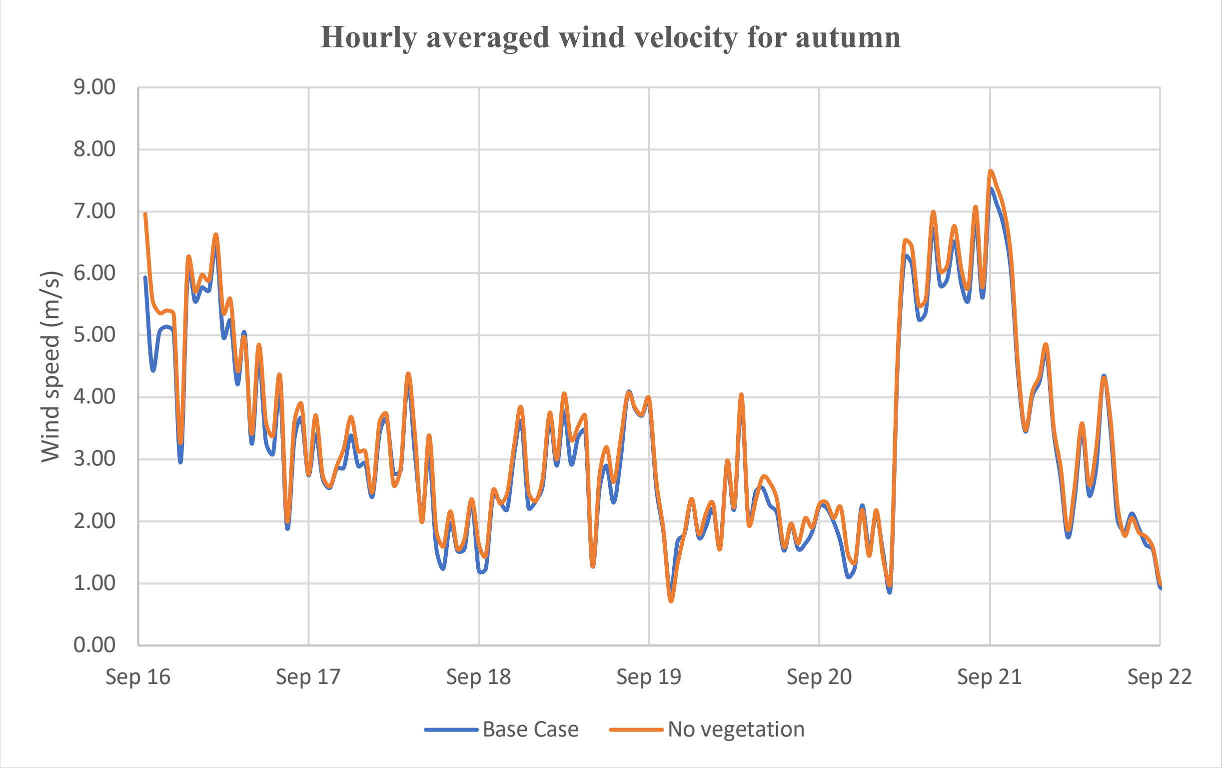


Figure 34: Comparative representation of wind velocity for a week in autumn for two scenarios.

The wind velocity with no vegetation seems slightly dominant. The average wind velocity for base case scenario is 3.1m/s, whereas the average wind velocity for no-vegetation scenario is 3.3m/s, which is higher by about 6.4%.

5.3 Building Energy Demand

5.3.1 Annual Simulation

The annual simulation of the representative building taking the weather data from two stations, viz., Værnes and Gløshaugen, gave the following results.

Table 10: Simulated building energy demand with weather data collected from two different stations.

Stations	Energy Demand (kWh/m^2)
Værnes	199.7
Gløshaugen	184.2

The energy demand simulated with the weather data from Værnes stations for the year 2020 is higher by 15.5 kWh/m^2 as compared to the energy demand simulated using the weather data from Gløshaugen weather station. This is an increase in building energy demand by 8.4%.

The HDDs are 11% higher but the energy demand is only 8.4% higher. One of the probable reasons could be that the thermal mass of the building is able to compensate the energy demand for short periods of time with low outdoor temperature.

Taking into considerations the future transformation into zero emission neighbourhood, this is a significant amount of energy wasted which can be avoided by taking microclimate into account for the calculation of building energy demand, which will save the cost both economically and environmentally.

5.3.2 Scenario Based Simulation

The CFD generated weather data collected at the representative building surface for two scenarios: base case and no-vegetation case are used as input data for climate and the energy demand is simulated for each scenario. The results are presented below.

Table 11: Simulated energy demand for two different scenarios.

Scenarios	Energy Demand (kWh/m^2)	
	Summer Case	**Autumn Case**
Base Case	5.5	3.7
No-vegetation	5.6	3.7

For summer, the energy demand with no-vegetation scenario is higher than that of the base case scenario by about 2%. Interestingly, however, for autumn, the energy demand for both the scenarios are equal.

This can be explained by breaking down the total energy demand into individual component of energy usage as in Table 12.

Table 12: Breakdown of total energy demand into individual demand category.

Energy Demand Category	Energy demand-Summer case (kWh)		Energy demand- Autumn Case (kWh)	
	Base case scenario	**No-vegetation Scenario**	**Base case scenario**	**No-vegetation Scenario**
Cooling	10803	11366	-	-
Heating	-	-	123	101
HVAC auxiliary	3027	3033	3175	3177
Lighting	7784	7784	7788	7789
Equipment	10722	10722	10728	10728

For the summer case (15th-21st June), there is high cooling energy demand but negligible heating demand. From these data, it can be interpreted that the lack of vegetation has resulted in the rise of temperature, thereby increasing the cooling demand. The base case scenario has, therefore, lower heating demand than the no-vegetation scenario. There is an increase in the cooling demand by 5.2% when there is no vegetation.

On the contrary, the autumn case (16th-22nd September) has heating demand with negligible cooling demand. The heating demand is not significantly high as compared to the cooling demand associated with the summer case. The base case scenario has higher heating demand than that of the no-vegetation scenario by about 20% but this is negligible when the heated floor area is large as the difference is only 19kWh which is 0.003 kWh/m^2. This again supports the statement that the lack of vegetation has resulted in higher temperature, thereby, reducing the heating demand.

5.4 Operative Temperature

The case study building is a 13 storied building and the operative temperature can vary with the building height and orientation. Therefore, the maximum operative temperature at ground floor, 6th floor and the top floor is extracted for the comparison and analysis.

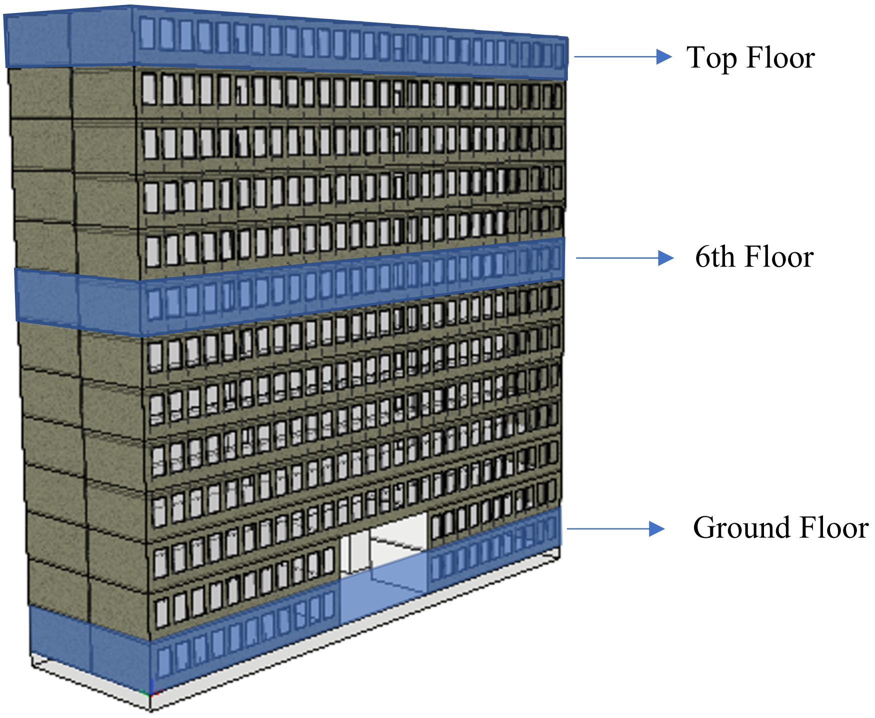


Figure 35: Different levels of floor selected for the operative temperature comparison.

5.4.1 Summer Case

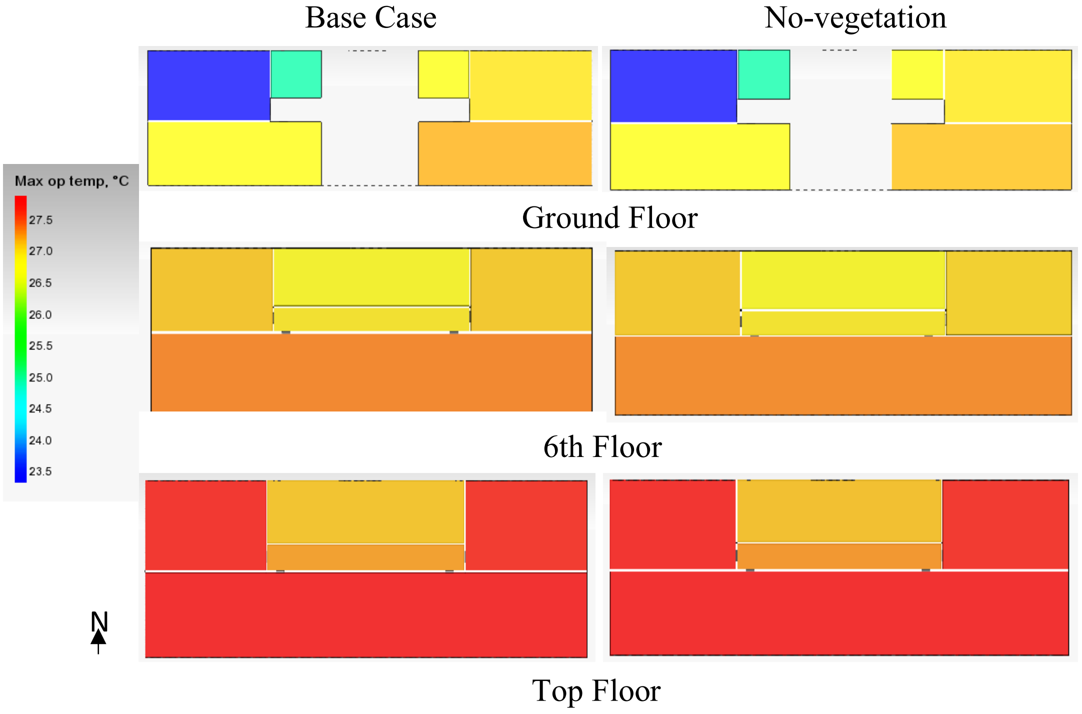


Figure 36: Maximum operative temperature at different floor level for summer case.

From Figure 36, it is evident that most of the south facing zones have higher operative temperature as compared to zones facing other directions. This is an indication of the impact of solar radiations on the microclimate as the zones facing south receive direct solar radiations. Similarly, zones facing the North have the lower operative temperature as compared to those facing other directions. This is because the northern facades do not receive the direct solar radiations. The results also show that the operative temperature is higher with the rise of building height. This difference is very evident in west facing zones which have a difference of about 3˚C between ground floor and top floor.

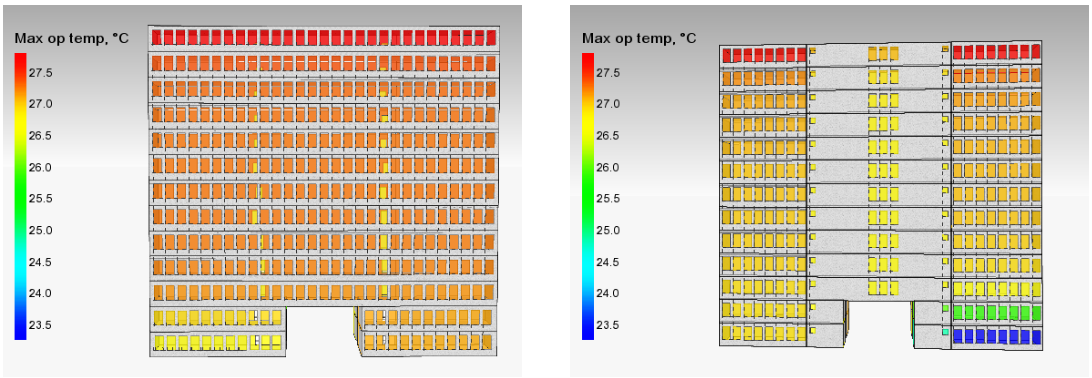


Figure 37: Maximum operative temperature at southern and northern facades for summer case.

5.4.2 Autumn Case

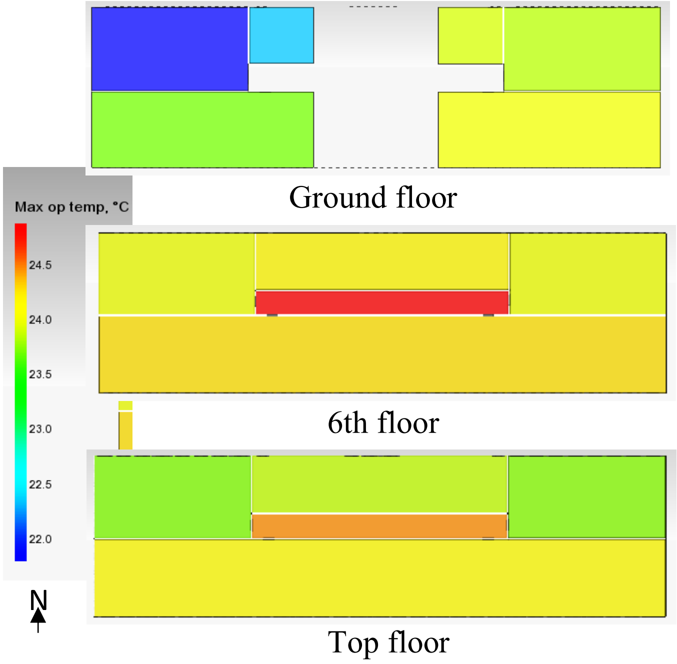


Figure 38: Maximum operative temperature for autumn base case scenario

Similar to the summer case, Figure 38 shows that, the southern zones have higher operative as compared to the zones facing other directions due to the exposure of the façade to direct solar radiation.

Unlike in the summer case which has higher operative temperatures at the top floor, autumn case has higher operative temperatures at the 6th floor. One of the reasons could be associated with the wind speed that the autumn case has higher wind velocity as compared to summer case by more than 1m/s. The wind velocity is lowered by the surrounding buildings for lower levels of the building, but it is prevalent in the higher levels of the building, causing cooling of the facades at the higher levels. This could mean that the ground floor should be having the higher operative temperatures than the 6th floor but the facades at the ground floor don’t receive enough solar radiations due to shadings from the surrounding buildings.

6. REFLECTION AND CONCLUSION

The minimization of the energy demand in a building is one of the major researches that the ZEN is undertaking to transition into a zero emission society. Therefore, every unit of energy reduced is of major importance. Climate plays a vital role in building energy demand. With urbanization growing at an alarming rate, the climate differs within a short scale of proximity due to several factors associated with the urban landscape. The temperature at the city is higher than the temperature at the nearby rural area.

Meteorological weather data recorded at one place defines a microclimate at that place within a radius of 2km according to the climatic scale defined by Orlanski (1975). Further away, the scale of climate changes to meso-scale and then to macro-scale covering thousands of kilometers of radius. In this respect, this thesis has looked into the different climatic data, collected at meso and micro scale to evaluate the impact on the building energy demand.

The general practice today is to take the weather data from the typical station for the energy design of a building. This practice largely ignores the impact of microclimate on building energy demand. For Trondheim, the typical meteorological data is recorded at Værnes which is about 26km crow-flight distance away from the city center and the landscape of Værnes is characterized by airport landscape with low rise building, surrounded by rural areas.

The results from this study showed that the climate at Gløshaugen is significantly different than that in Værnes. Gløshaugen campus has about 2˚C higher annual mean temperature than in Værnes. The heating degree days associated with the climate at Værnes is higher by 11% as compared to that of Gløshaugen. This shows that the buildings designed at Gløshaugen with the climate recorded at Værnes has a significant amount of energy being wasted. This could be avoided by simply taking the weather data at microclimatic level. In colder climate, the heat generated due to microclimatic factors can be used in building designs to lower the overall heating demand. It is obvious that the weather data cannot be recorded at every small area, but it is also important to consider that the weather data recorded at one kind of urban landscape is different from another landscape and this will result is inaccurate calculation of energy demand.

Further, the weather data from the CFD analysis is of major importance when it comes to detailed study of the impact of microclimate on building energy demand. The CFD analysis can also be useful in predicting the climate when the landscape of the city changes due to urbanization.

With the increasing rate of urbanization, the temperature in the cities is rising which will have a devastating effect on the climate change on the long run. Therefore, the importance of taking microclimatic parameters into building energy design is a one step ahead in achieving a zero emission neighbourhood.

The following recommendations can be proposed in the light of making a more energy efficient society in the future.

- The designers should take into account the local environment and local climate and explore the available possibilities to keep pace with the development of cities.
- Improve the environmental performance of the existing architectural projects by using the microclimatic impact in when there is a need for retrofit and major maintenance.
- Make efficient use of the available scientific tools and programs to efficiently model the climate and building energy demands such as CFD.
- Take advantage of the heat generated in urban landscape to minimize the heating demand especially in the cold climate.
- The educational institutes should take responsibilities of training of specialists and creating awareness programs to address the impact of microclimate through providing a practitional and educational backgrounds. This knowledge may help make critical decisions before regarding their designs.
- The government should take responsibilities in making decisions and policies for building infrastructures in accordance with the local climate so that the city is responsive to its climate.

Limitations and Challenges

There were few limitations and challenges faced during this study, some of which are:

1. The weather data collected from the Gløshaugen campus had many frozen values due to malfunctioning of the recording device. This was addressed through interpolating the nearby values and adjusting with the values from Voll station.

2. It was challenging to model the radiators in each zone in IDA ICE as there are several radiators used in the study building. This was addressed by using the default ideal heating setting in the IDA ICE because the main goal of the study is to evaluate the impact of microclimate (outer surrounding) on building energy demand.
3. It was difficult to find the detailed information of the study building. The drawings and constructional records were from 1960s. Norwegian standard NS 3031 was used to input some of the missing values such as air leakage and internal loads.

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