Evaluating the impacts of considering urban microclimate conditions on the accuracy of the Building Energy Simulation (BES) models

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Master thesis in Energy-efficient and Environmental Buildings
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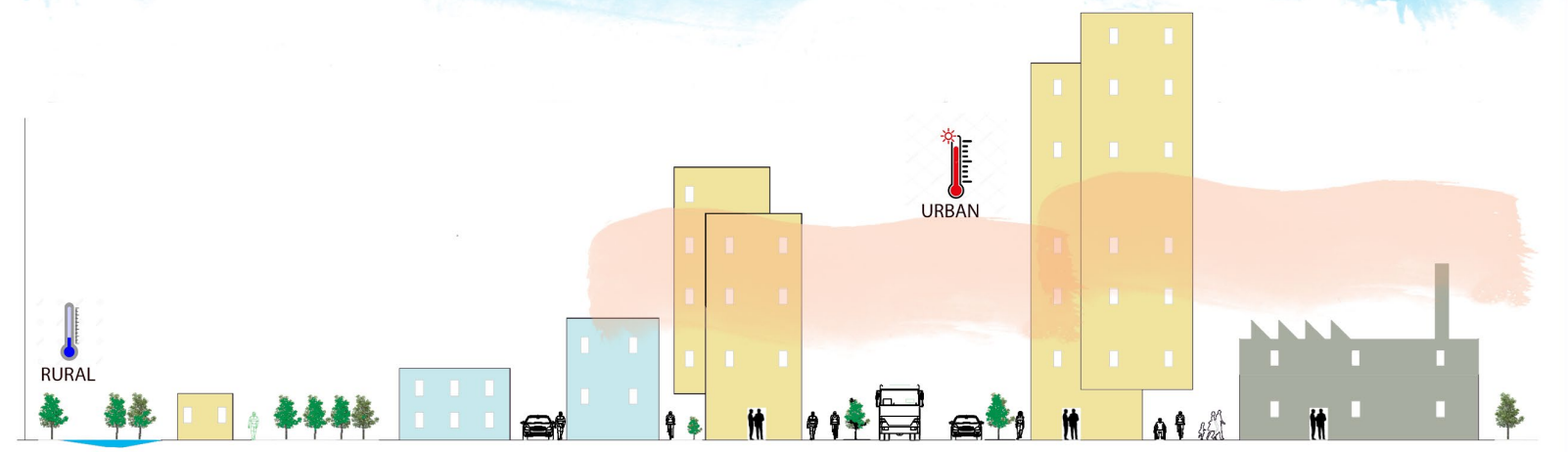

Lund University

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The degree project is the final part of the master programme leading to a Master of Science (120 credits) in Energy-efficient and Environmental Buildings.

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Keywords: Urban microclimate conditions, Building energy simulations, standard weather files.

Publication year: 2021

ABSTRACT

Following rapid urbanization and population growth in cities, many recent studies indicate the impacts of microclimate conditions on the energy performance of buildings. However, the methodologies and simulation tools used to evaluate the energy performance of buildings in urban settlements have overlooked the impacts of microclimatic conditions simply by the use of weather station data. This study aims to establish a comprehensive yet accurate approach that assists in building energy simulations (BES) based on precise microclimate data, focusing on significant variables such as local air temperature and wind speed. A methodology that couples urban microclimate models generated using both Gismo and Dragonfly are used to a case of M-Building located in Lund university main campus; this method uses the UWG generated weather data file from extreme microclimate conditions to evaluate the energy performance of the M-building in comparison with the standard weather station data (TMY). The urban microclimate weather file is then used as input to the BES, and the outputs validated by the actual measured energy demand of the target building.

This study shows a significant increase in the air temperatures and the lowering of the wind speeds, accounting for the local climatic conditions. Moreover, the cooling demands increased by 2.57% and 9.67% during the warm month and heating decreased by 1.92% and 2.07% during the coldest month. This means not considering the urban microclimate conditions could lead to biases in crucial decisions that affect the economy and the immediate surroundings.

Keywords: Urban microclimate conditions, Building energy simulations, standard weather files.

ACKNOWLEDGEMENT

I would like to thank God, whose guidance along the best pathway of my studies has made me realize the never filled room of growth in education as his counsel and care made abundant success throughout my academic life.

I would wholeheartedly pass my gratitude to my supervisor Vahid M. Nik for his vision; professional support and critique that helped me throughout this degree project and to my co-supervisor Javanroodi Kavan for his close and dedicated technical assistance. Together they made it possible for me.

I would also like to express my sincere gratitude to my beloved family and friends, for their unconditional support and prayers that have always been with me.

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ACRONYMS

UHI Urban heat island

BES Building energy simulation

TMY EnergyPlus Weather file

ED Energy demand

GR Global radiation

T Temperature [ºC]

T_{DNK} Dry-Temperature from a DNK Copenhagen weather file

T_{Malmo} Dry-Temperature from Malmö TMYx weather file

T_{Micro} Dry-bulb Temperature from the urban microclimate weather file

Annotations

Meso[1] Malmö airport station weather file TMYx.

Macro[2] Copenhagen airport station weather file TMY.

Micro Urban microclimate weather file with the UHI effect.

1. Introduction

1.1. Problem formulation

Trends in urbanization have been one of the most discussed topics in recent decades. An estimated half of the world population resided in urban areas in 2018(World urbanization prospects: the 2018 revision, 2019); this number will increase by over 60% by 2030(World Urbanization Prospects, 2018). This rapid urbanization and population growth have resulted in the urban fabric's design complexities that include urban buildings' forms, arrangement, and materials as architects and urban planners struggle to accommodate the population in sustainable, livable and healthy settlements. However, this practice has led to global climate change, a growing increase in energy consumption, and outdoor and indoor thermal discomfort.

Buildings use about 40% of the total energy demand in Europe(fernbas, 2020) and about 50% of the entire world's consumption(Global Status Report 2017, 2017). A large part was taken by space heating and cooling, decreasing and increasing (zz, 2015). Santamouris reported that in Europe 1°C rise in air temperature causes an increase in electricity consumption by about 1.7% (Santamouris, 2013). Studies showed that buildings forms, arrangement and materials influence the local climatic conditions (Gros *et al.*, 2016; Mehaoued and Lartigue, 2019; Waibel, Evins and Carmeliet, 2019). The physical characteristics of urban areas are referred to as 'urban morphology' in the current state of the art. The urban morphology consists of three main elements including urban form (e.g. architectural layout, density, height, etc.), function (e.g. building type, urban size, etc.), and structure (e.g. street canyon pattern, open spaces, etc.)(Javanroodi, 2018; Javanroodi and Nik, 2020). These urban characteristics relate to the growing global concern of thermal comfort as caused by urban heat island (UHI)(Yang *et al.*, 2019)

Due to the UHI effect in urban areas average air temperature gets amplified compared to rural areas (Tian *et al.*, 2021). Many studies have extensively evaluated its relation to the urban setting and the microclimate conditions. Studies show that UHI has significant effects on the energy performance of the buildings(Santamouris, 2014), an increase in cooling and decrease in heating demands(Cui *et al.*, 2017; Guattari, Evangelisti and Balaras, 2018) and a growing impact on outdoor thermal comfort(Taleghani, 2018).

1.2. General problem

Many recent research studies extensively studied the urban settings' as the source for the variations on urban microclimate and its impacts in the past decades based on different world locations. Researchers have quantified the effects of geometries, layout, and buildings on the local weather conditions(Allegrini, Dorer and Carmeliet, 2015; Deng, Wong and Zheng, 2016; Javanroodi, Nik and Yang, 2020). Furthermore, these studies have shown that the modifications can be on the significant urban climate parameters, such as air temperature, wind speed and global solar radiation. Studies show that building materials such as concrete tend to trap heat, and building layout can lead to wind-blocking effect causing lower wind speeds. Altogether, these cause low convective heat transfer that contribute to the rising of urban temperatures. Moreover, it is proved to have both direct and indirect effects on the energy use of the buildings in its context(Allegrini, Dorer and Carmeliet, 2012; Hong *et al.*, 2019; Javanroodi and Nik, 2019). Therefore, recent studies have emphasized the growing necessity for considering the local climatic condition when building energy simulation to analyze the energy performance(Skelhorn, Levermore and Lindley, 2016).

1.3. Specific problem

Although recent studies have raised a significant concern of the need for accuracy while performing building energy simulation (BES)(Liu *et al.*, 2015; Allegrini and Carmeliet, 2018), still the available developed advanced tools overlook the importance of adopting real-time weather data for the accuracy of the BES. These tools make use of the commonly available weather data sets such as typical meteorological year (TMY) and international weather for energy Calculation (IWEC) that do not reflect real climatic situations of the urban context(Pisello *et al.*, 2015; Gobakis and Kolokotsa, 2017); as a result, essential energy decisions are being compromised or underestimated. Researchers suggest that building energy simulation can vary to 5% and 7% using local climatic data and TMY data, respectively(Bhandari, Shrestha and New, 2012).

1.4. Objectives.

Following a thorough literature review, there has been an extensive investigation on the effects of microclimate on the energy performance of buildings and thermal comfort. However, there is an evident lack of research on the significant influences of accurate microclimate data on the building energy simulation to evaluate the building's energy performance.

The supreme objective of this study is to evaluate the impacts of considering urban microclimate conditions on the accuracy of the building simulation when analyzing the energy performance of M-building located on the campus of Lund University in Sweden.

1.5. Scope

This study investigates the enormity of microclimate impacts on the energy performance of M-building as contributed by the variations of the main climatic variables. The assessment based on three different weather data sets.

1.6. Significance and limitations

The author conducted the project through coupled urban microclimate and BES, primarily based on numerical simulations, as measured data were insufficient. The author used weather data sets from nearby the case study location to generate a local climatic condition due to a lack of specific weather data from a particular study location. However, some essential inputs for the BES were insufficient, as outlined in Table 1. 1.

Table 1. 1 M building Data availability

M Building	
Data	Availability
Construction details	Insufficient
Cooling demand	Sufficient
Heating demand	Sufficient
Electricity production	Sufficient
Electricity consumption	Insufficient
HVAC System	Insufficient
Schedule	Insufficient

1.7. Research questions

This study aspires to provide answers to the following questions:

1. The difference in the central climatic variables between local conditions and those recorded by the rural weather stations.
2. The immensity of the urban microclimate conditions influences the accuracy of the building energy simulation.
3. Potential energy generation through renewable techniques as subjected to the local climatic conditions.

2. Background Knowledge

2.1. Microclimate and its Impacts

According to the American Meteorological Society (AMS), microclimate refers to the air space between the earth's surfaces extending through the edge of the underlying surface. Microclimate has been one of the growing researched topics in recent decades(Stewart and Oke, 2012; Hebbert and Mackillop, 2013; Mills, 2014), the Urban climate being the most extensively studied type of microclimate(Glossary of Meteorology, 2012) mainly associated with the UHI, thermal comfort and energy performance of buildings.

A microclimate is defined as a meteorological state subjected to building Energy (Toparlar *et al.*, 2018). In this regard, it is evident and vital to consider urban microclimate conditions on the accuracy of building energy simulation studies to avoid biases of the energy performance prediction. Understanding microclimate, these studies have focused on investigating the behaviour of the significant parameters that include air temperature, wind speed, RH and global radiation in different climatic locations.

2.2. Urban Heat Islanding

Recent studies show that the UHI results from compact urban features such as urban forms, layout, materials and human activities. Researchers have primarily investigated the impacts of these features on local microclimate in the past decades. (Bakarman, 2014; Taleghani *et al.*, 2015; Javanroodi, Mahdavinejad and Nik, 2018; Taleghani, 2018) As UHI is concerned, it is evident that air temperatures tend to be higher and wind speeds low in urban areas compared to rural areas; this has resulted from urban areas trapped in solar irradiation and low convective heat transfer due to wind sheltering(Xie *et al.*, 2020). As these local microclimate variables are modified(Theophilou and Serghides, 2014), they affect the building energy production and consumption(Javanroodi and Nik, 2019; Shi *et al.*, 2019). For this reason, the use of commonly available weather data becomes unfit in predicting the accurate energy performance of buildings. Therefore, it is evident that using on-site or local weather data for building energy simulation provides accurate results.

2.3. Building energy simulation accuracy

Recent studies raised concern for the BES accuracy, considering local climatic conditions has been at the top of the list as one factor that could help mitigate biases in the BES results and increase the reliability of the BES models. However, the problem persists, raising more questions on the BES inputs assumptions during the early design stage. In this regard, researchers have investigated the effects of early design assumptions in the BES models. These studies show that unfit inputs cause faults between simulated and measured data(Wall, 2006; Menezes *et al.*, 2012). Additionally, a study by (Daly, Cooper and Ma, 2014) shows that the case building's final energy demand can vary by more than 50% of the BES model accounting for the assumptions. These studies outline that the final energy demands of the BES models vary significantly from monitored data when parameters like solar transmittance values, air change and flow rates, wind speed, solar radiation, envelope properties, HVAC heat recovery efficiency, heat gains from both equipment and people and user behaviour (Molin, Rohdin and Moshfegh, 2011; Dodoo, Tettey and Gustavsson, 2017).

2.4. Urban microclimate Tools/Models

Different studies have led to the development of tools that intend on providing almost suitable methods of evaluating and assessing the impacts of considering microclimate conditions towards the accuracy of building energy performance simulations (EPS).

2.4.1. Urban weather generator (UWG)

Researchers developed this tool to predict the average urban microclimate conditions using the commonly available weather files EnergyPlus weather files (EPW). As seen in Figure 2. 1, This tool uses the urban building geometry, vegetation covers thermal properties and building use and systems to reflect the urban climatic situation (Bueno *et al.*, 2012; Bueno, Nakano).

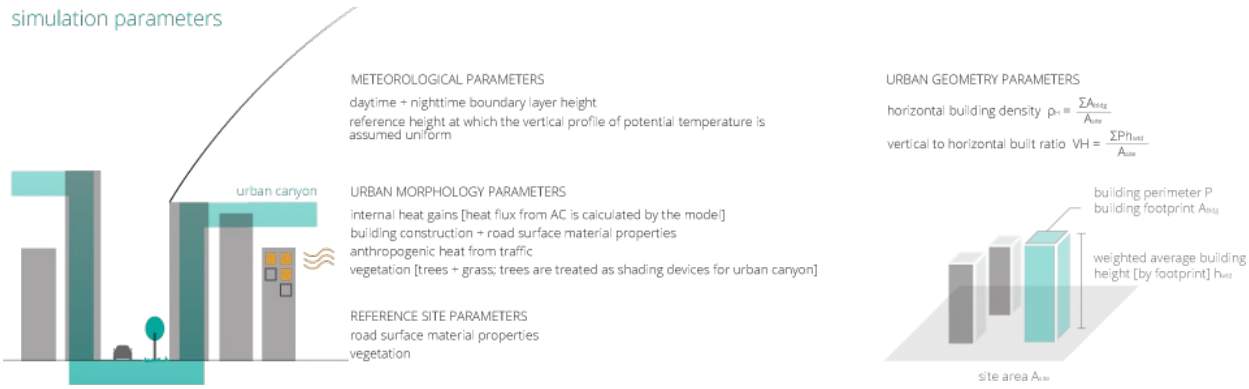

Figure 2. 1 Urban weather generator inputs by Bueno

2.5. Reference Weather Data Sets

Already in the '90s, an attempt to modify the weather data to represent at least the average weather condition within a given climatic location was performed. It included the development of sets such as TMY2, CWEC, and WYEC2, but still, these weather data sets were controlled and limited; hence did not consider the impacts of actual on-site climatic conditions.

2.5.1. International weather for energy calculation (IWEC)

According to ASHRAE, these are weather files based on different world locations used for energy simulations. They contain hourly surface data from a national climate data centre of a particular area. These files can contain recorded weather observation of at least 12 to 25 years(ASHRAE (IWEC2), 2021).

2.5.2. Typical meteorological year (TMY) and (TMYx)

Every location has weather data; all these data are typical meteorological year (TMY) in a format, which supports energy simulation, mostly EPW setup. There are two kinds of TMYs, a TMYx measured for the entire record period of over 30 years, referred to as TMY and a TMYx of which include data sets measured only in not more than 15 years. The currently available TMYx is from 2004-2018(climate. onebuilding, 2021).

2.6. Solar energy use

2.6.1. Global solar radiation

One key aspect of solar energy use is the amount of global solar radiation falling on a particular location, customarily termed as threshold measured in kWh/m^2. Global solar radiation must be extensively investigated to fully utilize solar energy as it differs from time and place to place. A recent study(Kanters and Wall, 2014) based on the Swedish context has investigated the suitable threshold needed for a potential surface, as seen in Table 2. 1.

Table 2. 1 Threshold values for different categories (values in kWh/m^{2}a).

	Unsuitable	Suitable	Suitable	Suitable
		Reasonable	Good	Very good
Façade	0-650	651-900	900-1020	>1020
Roof	0-800	800-900	900-120	>1020

3. Methodology

This chapter recounts the methodology used to gauge the impacts of considering urban microclimate conditions on the accuracy of the building energy simulations. This section contains five subsections that describe the project as devised, Case building description and energy modelling schematic workflow, urban modelling, urban weather data generation and Computation fluid dynamics modelling.

3.1. Tools and Software

In undertaking this thesis's aim, the author uses many softwares to perform different tasks. These included software for climate studies, urban studies, building energy simulations, CAD tools for drawings and 3D modelling, and analysis tools, as discussed below.

4. Autodesk AutoCAD

AutoCAD is a computer-aided design tool, and in this thesis, the author used this tool to view all the construction drawings of the case building that the Akademiska Hus provides in a DWG format.

- Archicad

ArchiCad is a BIM tool for architectural preliminary, detailed, and construction drawings. It incorporates an interface used for 3D modelling and energy simulations. In this thesis, the author used ArchiCad for 3D modelling of the target building and the surroundings.

- Rhinoceros

Rhinoceros is a 3D computer-aided design software that uses a mathematical language to generate 3D geometry(Associates, no date). The author mainly used Rhinoceros for the target building modelling and different climatic visualization integrated with the grasshopper.

- Ladybug

A ladybug is a handy tool in a detailed analysis of climate data. It uses EnergyPlus weather files (EPW) to customize and visualize 2D and 3D climate variables that help in the design process(ladybug, 2021). The author used ladybug to perform different tasks such as solar radiation

studies and visualize various environmental data. Ladybug has also aided the author with wind and radiation analysis.

- Honeybee

In this study, the author performed all energy calculations with the help of a grasshopper plugin, Honeybee, which uses EnergyPlus or Open Studio to run and visualize energy results(Honeybee, 2021).

- Dragonfly

Dragonfly is a plugin used to estimate and predict climate scenarios such as urban heat island and factors influencing the local climate. In this thesis, the author used Dragonfly to create local climatic conditions with the help of an urban weather generator engine(Dragonfly, 2021).

- Gismo

Gismo is a grasshopper plugin used to generate an urban environment that includes terrain, building geometries, trees, roads and rivers based on the latitude-longitude coordinates and radius of a location. This thesis used gismo to create the urban context for urban microclimate studies(Spasic, 2021).

- Microsoft Excel

The author used Excel to analyze the data outputs from different simulations and compare them to the measured data.

4.1. Schematic Framework

Below is Figure 3. 1 showing the workflow of the study toward achieving the research task.

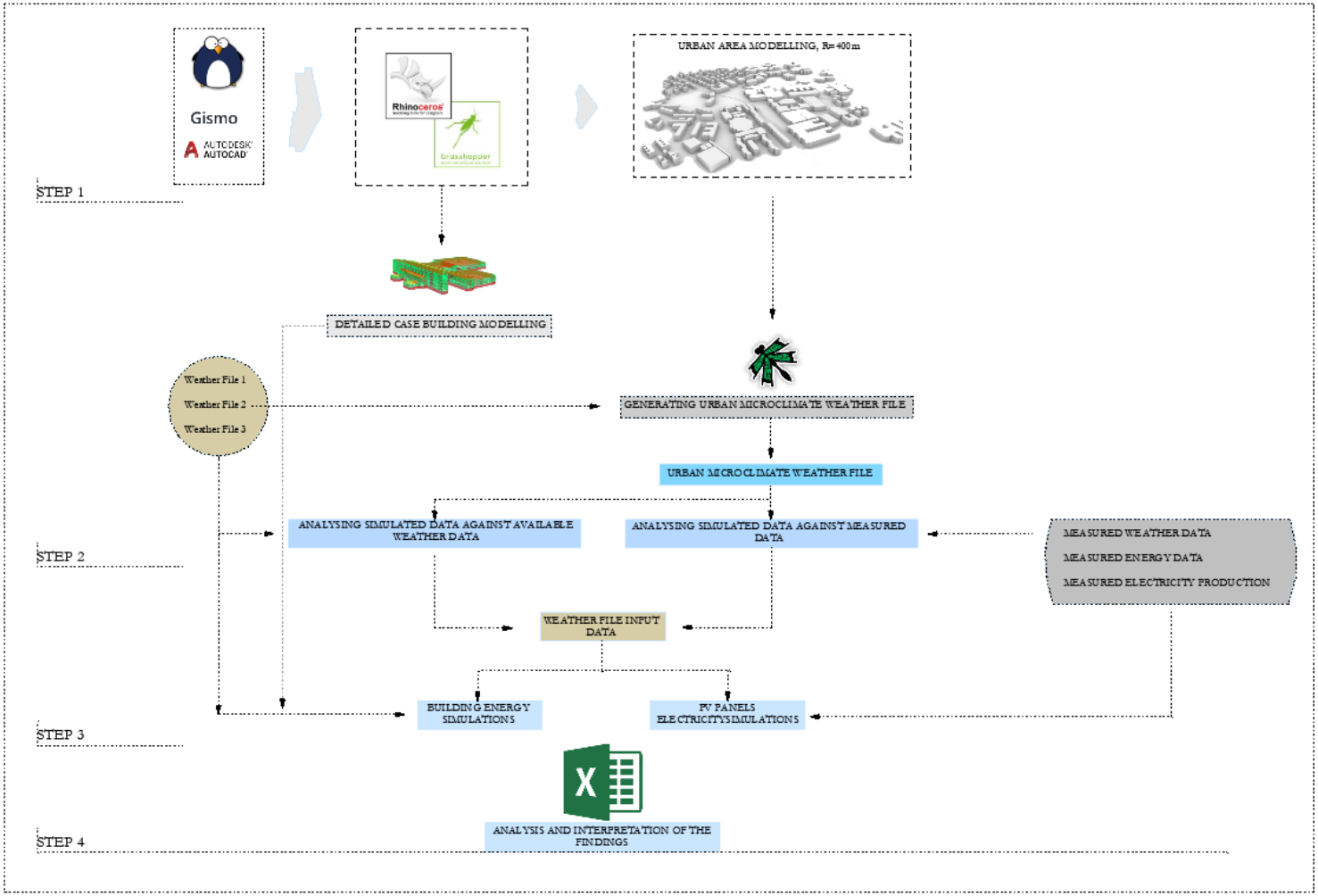

Figure 3. 1 Schematic workflow (picture by author)

4.2. Case Building description

M Building stands for the Mechanical and Industrial Management Engineering Building centre, located in the southern end of the Lunds Tekniska Högskola (LTH) campus at Latitude 55.71 N and Longitude 13.21E, shown by number 12 in Figure 3. 2 from the LTH virtual model.

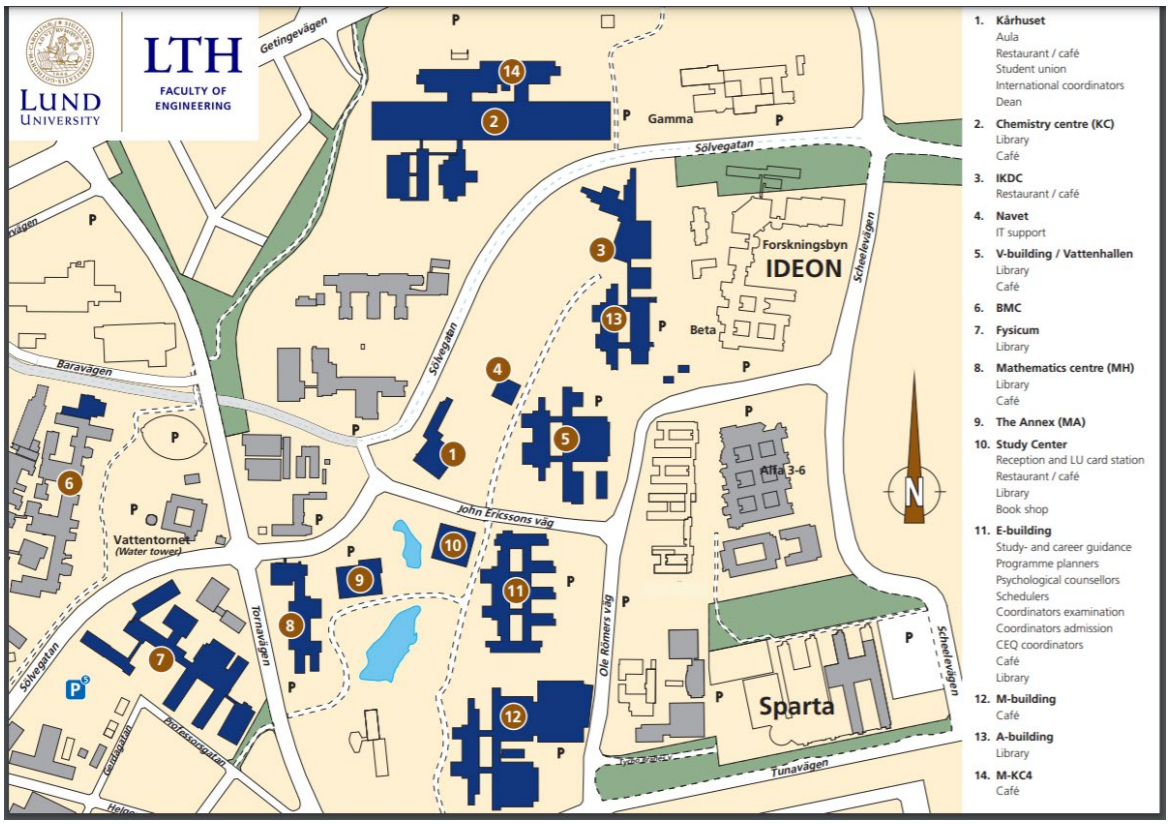

Figure 3. 2 LTH campus map from student website LTH

The building materials used were red bricks and flat roofs matching the surrounding context. On the north part, it is close by the A-building and Spatra on the east; however, the immediate surroundings are green grass, trees of approximately 6m high, and a water pond on the building's northwest side see Figure 3. 3.

Figure 3. 3 Aerial views of the M-building from aerial tour developed y LTH

Table 3. 1Table Building Features and Location

Case building's reference features	
Location	LTH Campus
Longitude	55.70976588872671,
Latitude	13.210523749857371
Elevation above sea level	65m
Orientation	-
Floor Area	38561.4 m^2.

4.3. Urban weather generator modelling

The urban model was prepared in stages to reflect the actual situation at the LTH campus. The author used the Gismo software script to create an urban context following the prescribed requirements. The urban microclimate studies used an urban model with 400m from the target building, made only from 2D elements that included the buildings' shapes; roads, trees, and terrain (see Figure 3. 5. Afterwards, a different ladybug script was used to create surfaces and elevate building geometries from the building shapes using a random average building height of 20m see Figure 3. 4.

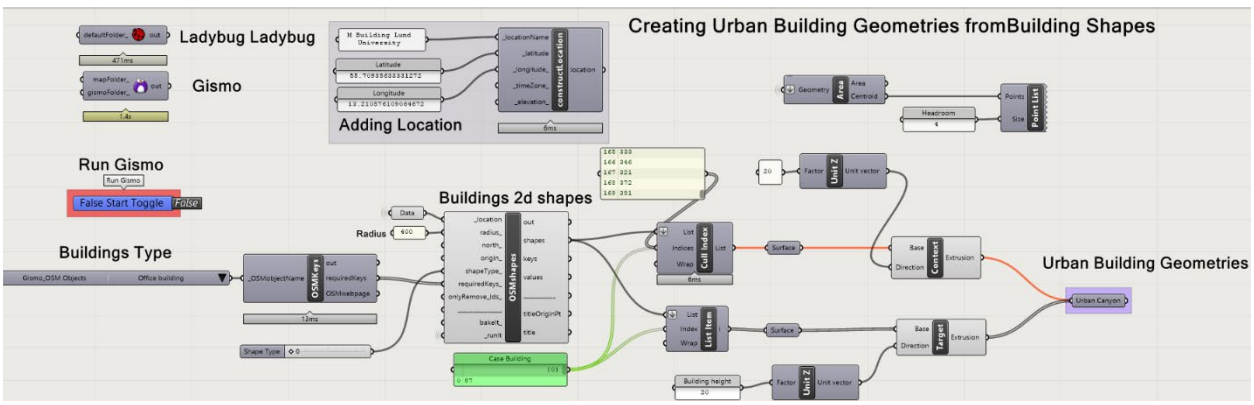

Figure 3. 4 Script for creating an urban model from 2D buildings shapes generated by Gismo

Figure 3. 5 Urban Model vie with Building forms generated By Gismo for UWG Urban weather data set generation (picture by author)

The author used a python application to model the urban heat island effect, and a UWG initially developed (Bueno Unzeta 2010). This application uses the rural and commonly available weather files such as EPW EnergyPlus and the urban fabric to generate a particular area's average local climatic conditions see Figure 3. 6.

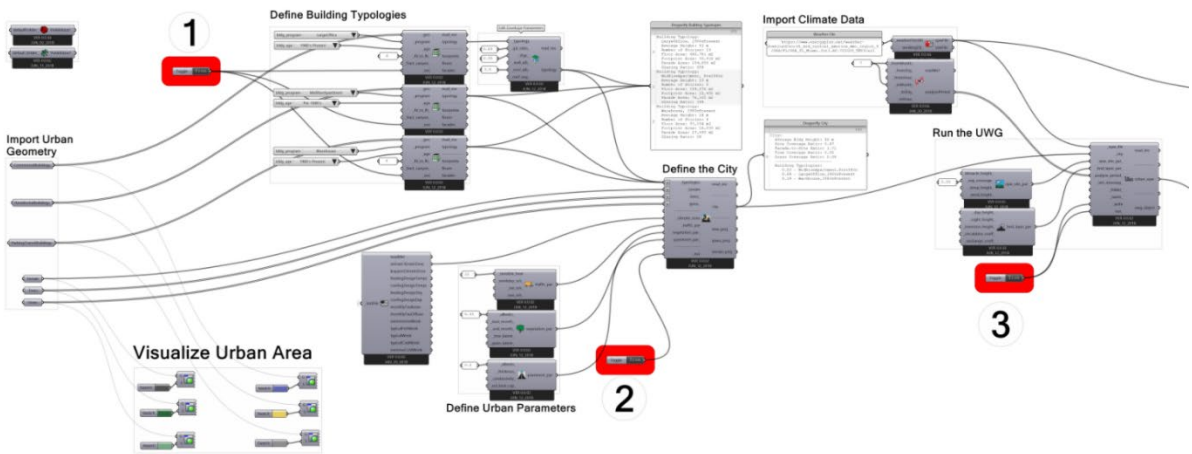

Figure 3. 6 A script to generate a UHI weather file is available (Hydra, 2021)

The UWG uses specific climatic data depending on the climatic zones. According to standard 169, 2006 (ASHRAE, 2021), the LTH would be categorized in a 5C climate zone. The author modified the available script accordingly to generate the microclimate weather file. This microclimate weather file validated against the measured data and the commonly available weather files to determine the magnitude of local conditions, particularly on the building energy simulations (BES).

Table 3. 2 Input parameters for UWG

Description	Inputs
Latitude	55.70935633331272
Longitude	13.210576109064672
Building program	Large office
Buildings Height	5-20m
Climatic zone	5C

4.4. Case Building Energy Modelling

Performing energy simulations of the case building (M-huset) required detailed energy modelling. The author used detailed architectural drawings by the Akademiska Hus to model a realistic building geometry of the case building. The author used the measured data to validate the simulations results. Accomplishing the thesis goals, the author used a well-devised procedure is to attain the desired results see Figure 3. 7.

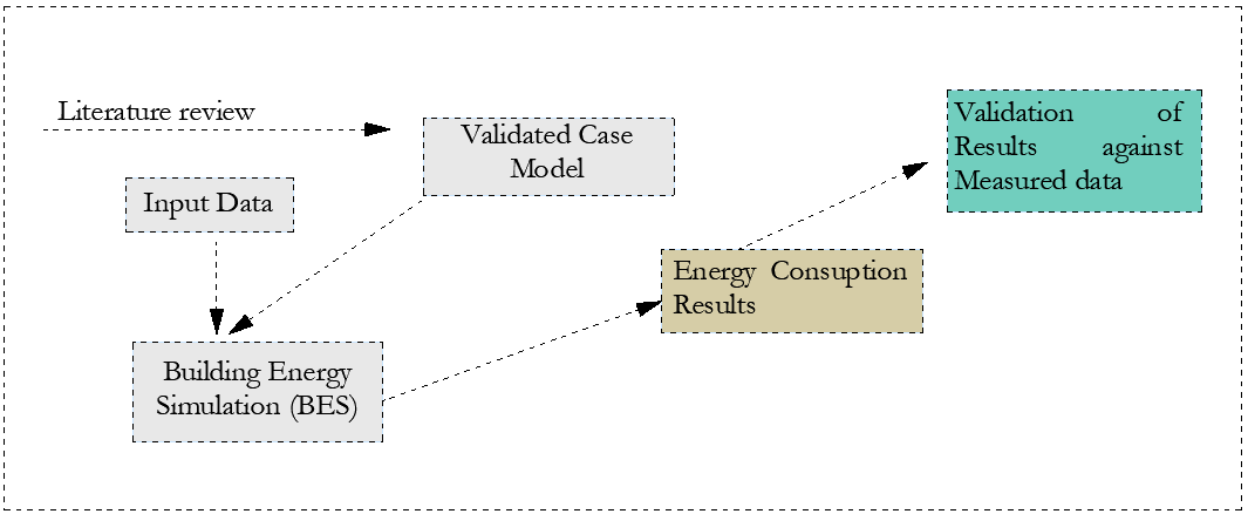

Figure 3. 7 Schematic workflow for building energy simulation

Weather data sets

This study based on four different weather data sets to evaluate the magnitude of the impacts of the urban microclimate conditions. Using an urban weather generator engine (UWG). A weather file was generated in a 400m radius from a target building using the urban fabrics that included buildings, trees, roads, water bodies, construction materials and TMYx weather from Malmö as an input file.

The key variables of the microclimate weather file created were then analyzed in comparison with the DNK (TMY) and Malmö (TMYx) files from weather stations (climate.onebuilding, 2021). The newly generated weather file was validated with the on-site measured data of 2015-2016 recorded with the Davis vintage Pro weather station (Davis Instruments, 2021) for accuracy and reliability. These microclimate weather data were used as inputs for both the building energy simulations and solar energy studies.

4.4.1. Building Geometry

Based on the available detailed drawings from Akademiska Hus, the target building geometry was modelled precisely in Rhinoceros integrated with grasshopper to create an energy model for the building energy simulations. The case building was segmented into several energy zones see Figure 3. 8, which were later assigned with an occupancy schedule, internal loads, infiltration, and HVAC system as per the available data obtained from Akademiska Hus and based on the author's assumptions.

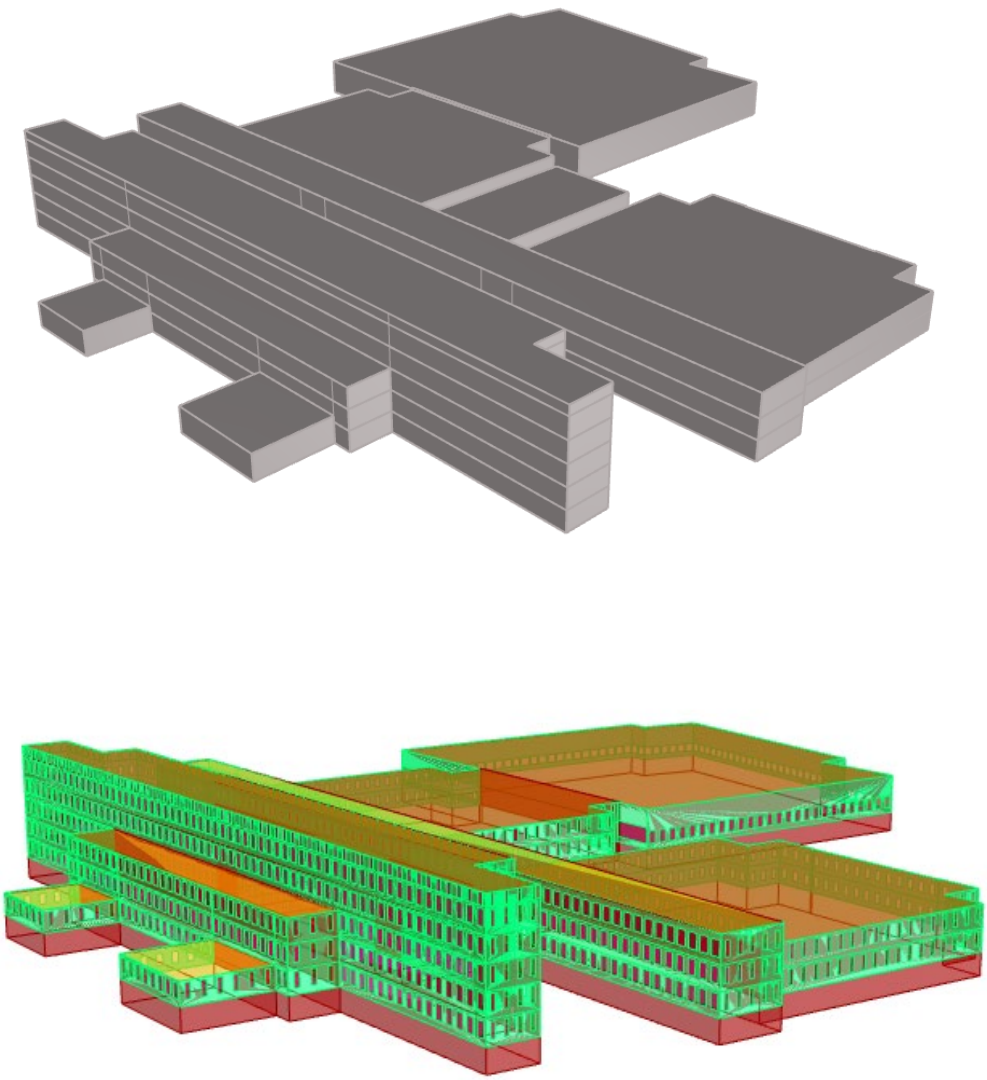

Figure 3. 8 Energy simulation model as modelled in rhino (picture by author)

4.4.2. Building Envelope

The construction properties of the target building were inherited from previous research performed by(Huang and Yang, 2017) and used as references see Table 3. 3 Building envelope construction properties.

Table 3. 3 Building envelope construction properties.

Building Envelope	M-Huset U-Value [W/(m^2 K)]
External Walls	1.2
External walls below ground	0.21
Roof	0.1
External Slab	2.7

4.4.3. Windows' properties

Windows exact sizes and numbers were obtained from the detailed architectural drawings provided by Akademiska Hus in a DWG format. The thermal properties of the windows were based on the author's sound assumptions. They were assumed 1.3 W/ (m^2K) and 2 W/ (m^2K) for both the window's glazing and frame.

Table 3. 4 Windows's construction properties adopted from (Huang and Yang, 2017)

Windows	**Area [m^2]**	**U-Glass [W/(m^2 K)]**	**U-Frame [W/(m^2 K)]**	**U-Total [W/(m^2 K)]**	**U*A [W/K**
North	360.70	1.30	2	1.37	494.16
East	714.73	1.30	2	1.37	979.18
West	372.49	1.30	2	1.37	510.31
South	962.90	1.30	2	1.37	1319.17
Total	2410.81	1.30	2	1.37	3302.81

4.4.4. Infiltration mode

The infiltration mode was set based on Swedish standards that are air change per hour (ACH), which was 0.6ACH at a pressure difference of 50Pa according to BBR(Boverket, 2015).

4.4.5. Operating Schedule

The operating schedule adopted was provided by Akademiska Hus, which indicates that offices are occupied from 08:00 to 17:00 on weekdays. The rest of the functional spaces would be occupied from 08:00 to 20:00 except for the weekends where the building is considered unoccupied.

4.5. Solar energy modelling

This study involved modelling the target building in rhinoceros to perform the annual solar radiation analysis. The amount of solar irradiance would determine potential surfaces to install the PV panels see Figure 3. 9. In addition, based on a scale of threshold values received on roof surfaces, the solar energy use simulations would be performed to determine possible monthly electricity produced by the installed PV panels.

The target building has Mono X neon PV panels with 191 kWp installed. However, this study would neglect the PV cells technologies and base on utilizing both the available weather files and a newly generated weather file to access the solar potential and PV cell electricity production. The aim is to tell the difference in urban microclimate conditions compared to the standard weather files that most solar energy simulations tools use.

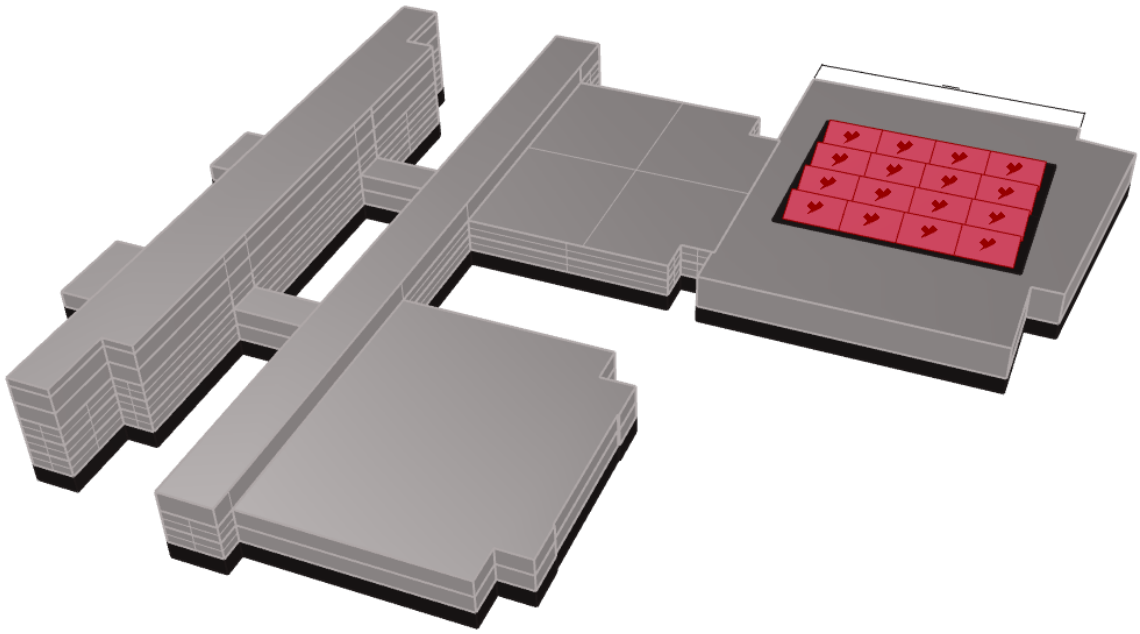

Figure 3. 9 Rhino modelled PV panels matching the existing (by Author)

4.6. Shading effect

Shading is one of the essential aspects to account for when performing annual irradiation analysis. Surroundings that include trees and buildings were modelled in rhino to add up the effect in the electricity production since the weather files generated already accounted for this effect.

4.7. Solar angle parametric study

Solar energy production by a PV panel involves complex physics and technology. However, this study would base on solar angle θ as one of the vital aspect determining the output of the solar cells, and for the fact, it has a direct connection to the global solar radiation as one of the critical variables affecting the local climatic conditions. According to (Duffie and Beckman, 2013) solar angle, include factors such as the solar azimuth γs, solar height αs, the hour angle ω, the declination δ, solar time and zenith angle θz. Altogether, they ensure the most negligible solar radiation is achieved from different sun position at different times of the day and year for the PV optimum output see Equation 1.

Solar angle $\theta = \arccos(\sin(\theta z)\sin(\beta)\cos(\gamma s-\gamma) + \cos(\theta z)\cos(\beta))$ (10) Equation 1

β= tilt of the surface from the horizontal, $0^{o} \leq \beta \leq 180^{o}$
γ= the rotation from the south (azimuth) (west is positive), $-180^{o} < \gamma \leq 180^{o}$

This parametric study based on the already installed PV panels on a high potential roof surface. PV panels were tilted from 0° to $45^{o,}$ facing south. All three weather files were used to determine what weather file would yield enough monthly electricity to cover the consumption. A grasshopper script was used for the solar energy simulations see Figure 3. 10. The monthly electricity produced by the PV panels were plotted against the solar cells produced data for validation.

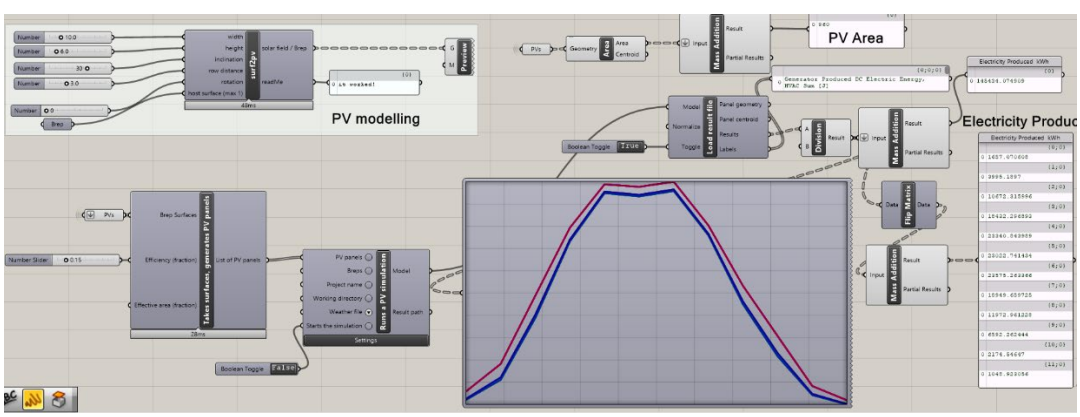

Figure 3. 10 Script to model and generate electricity

5. Results

This chapter explains the findings obtained from a profound literature review and a well-devised methodology. This part will cover the urban microclimate simulation results of essential climate variables and building energy simulations (BES) results. The analysis is based on the significant difference made considering microclimatic conditions. Lastly, this chapter will show the results of the solar energy potential due to the microclimatic conditions of a case location.

5.1. Urban Microclimatic Analysis

The essential factors that directly affect the building energy simulations (BES). The author analyzed these parameters in two ways, first by comparing readings on the hot and cold days of both the commonly available weather files(TMY) from the weather stations and the weather file generated from local conditions of the case area (LTH campus). Secondly, the author validates the local microclimate results obtained by comparing them to the measured data received.

5.1.1. Comparison of the applied weather files

A comparison between the new urban microclimate weather file and the standard TMY files based on important climatic variables, dry bulb temperature, wind speed and global solar radiation considering the impacts of urban microclimate is discussed below.

Air Temperature

Air temperature is one of the evaluative factors affecting building-related systems; hence, it is a robust parameter considered when analyzing the impacts of microclimate and the accuracy of the building energy simulations. As mentioned before, for better presentation and understanding, both the warmest day and coldest day were used to show the ambient temperature variations of the LTH Campus within a 400m radius from a target building M-Huset. Surface temperatures can be found in Appendix F.

Moreover, Figure 4. 1 shows that the monthly average dry-bulb temperature of the newly generated urban weather file is 1°C higher than the DNK and Malmo weather files for all cold months, 2°C, and 4°C higher for the warmest months, respectively.

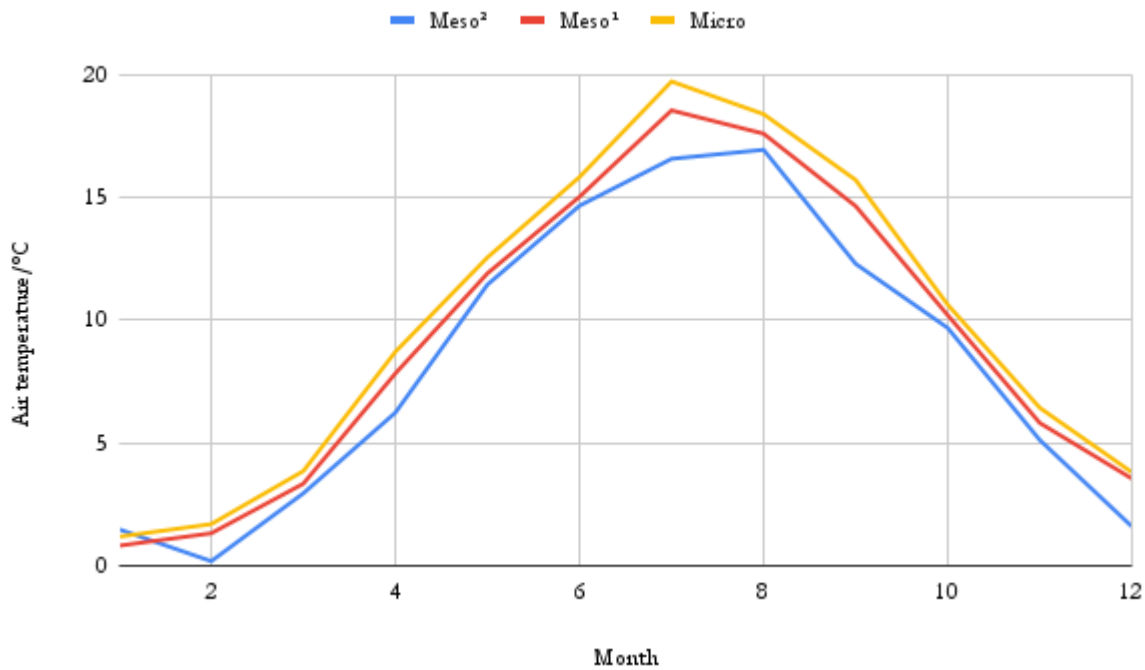

Figure 4. 1 Average monthly dry bulb temperature

The variations are more evident in Table 4. 1 shows the diurnal air temperature variation. The microclimate file's daily average dry bulb temperature is higher than the weather station files, which do not consider the effects of local conditions see Appendix A for annual hourly results.

Table 4. 1 Average daily and nightly air temperatures

	Average daily Air Temperature (7:00.a.m to 7:00 p.m.)			Average Nightly Air Temperature (01:00.p.m to 6:00 a.m.)		
Temperature as per weather file	Max	Ave	Min	Max	Ave	Min
T_{DNK}	20.4	7.5	-8.9	19.6	6.7	-8.1
T_{Malmo}	19.9	7.8	-12.4	19.5	7.4	-11.4
T_{micro}	23.9	8.5	-9.5	23.2	8.6	-8.9

As seen in Figure 4. 2, on a cold day, air temperature varies for about 5ºC and 2ºC between the microclimate and the DNK (TMY) and Malmo weather files (TMYx). Respectively.

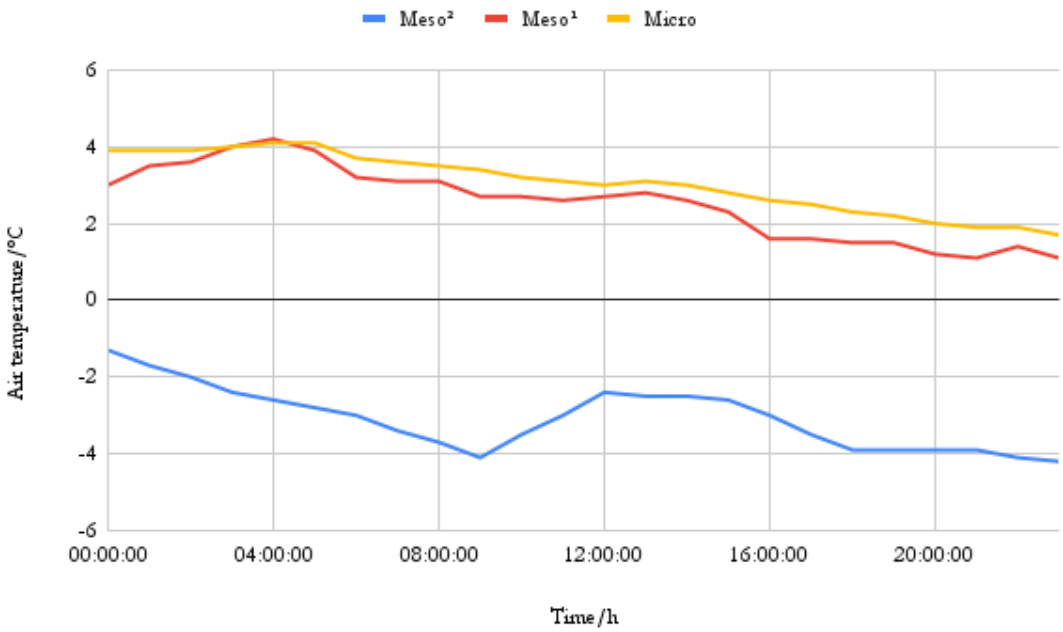

Figure 4. 2 Air temperature on January 21

On the summer day Figure 4. 3, however, the air temperature difference is about 3ºC slight, with the DNK weather file slightly higher than the rest of the weather files.

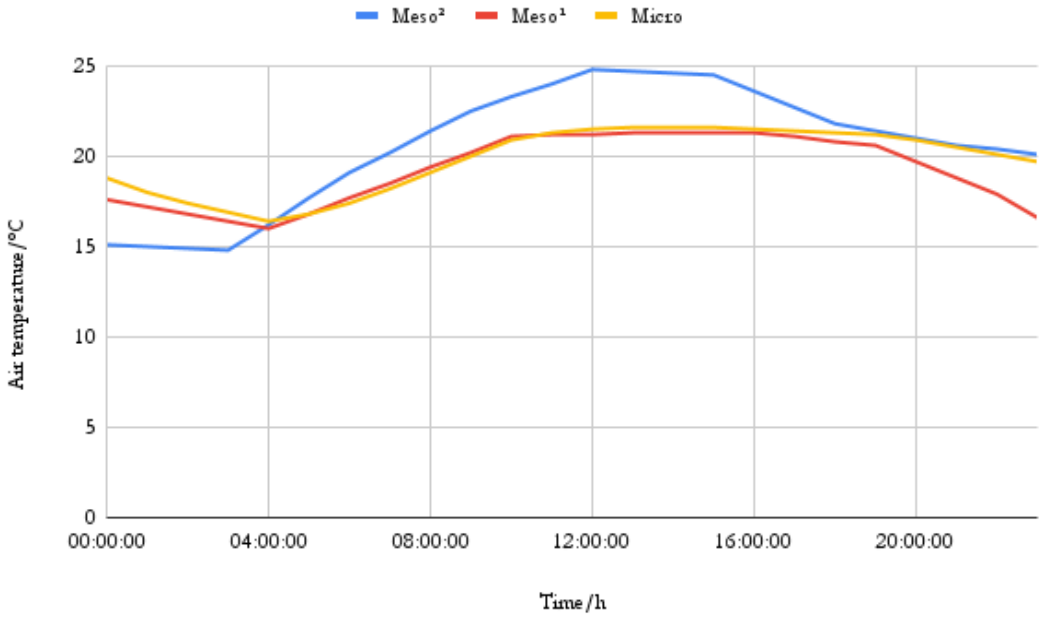

Figure 4. 3 Air temperature on July 14.

Wind Speed and direction

Figure 4. 4 shows a relatively stable pattern of wind velocity with the urban microclimate file than the weather station files during the coldest day. Respectively, a range of 2m/s-4.3m/s is observed in both daytime and nighttime. During a warm day, see Figure 4. 5, the wind velocity appears to be relatively stable with a slight difference of 2m/s. However, at nighttime, the wind speed falls to 0.5m/s and rises to 7.2m/s for the microclimate and standard weather station data, respectively. More variations can be seen in hourly results. See appendix A.

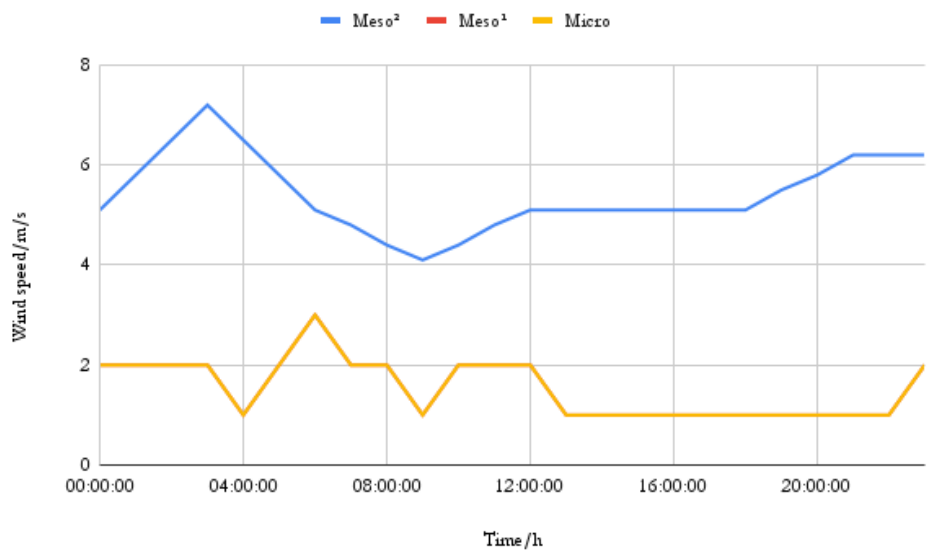

Figure 4. 4 Wind speed on January 21

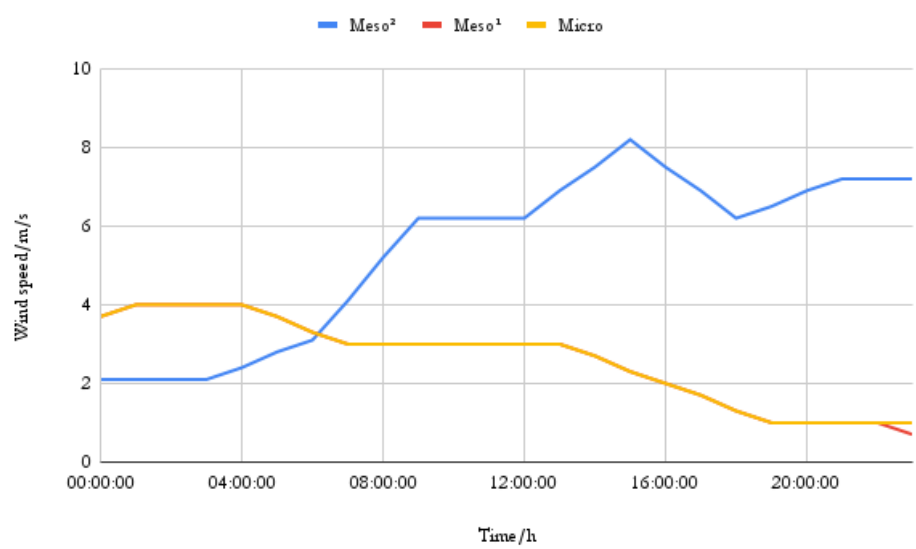

Figure 4. 5 Wind speed on July 14.

Cloud cover

Since most of the traditional weather station and simulations tools do not account for global solar radiation, this study uses cloud cover analysis as one of the key factors affecting global solar radiation to understand its pattern. An annual hourly cloud cover was performed with both the urban microclimate weather file and the standard weather file (meso^2). Figure 4. 6 shows more cloud cover during winter months and less cloud cover in months, which allows more solar radiation, during daytime. However, Figure 4. 7 shows rather a scattered cloud cover pattern throughout the year, as for this reason solar radiation with the standard weather file (meso^2) is observed.

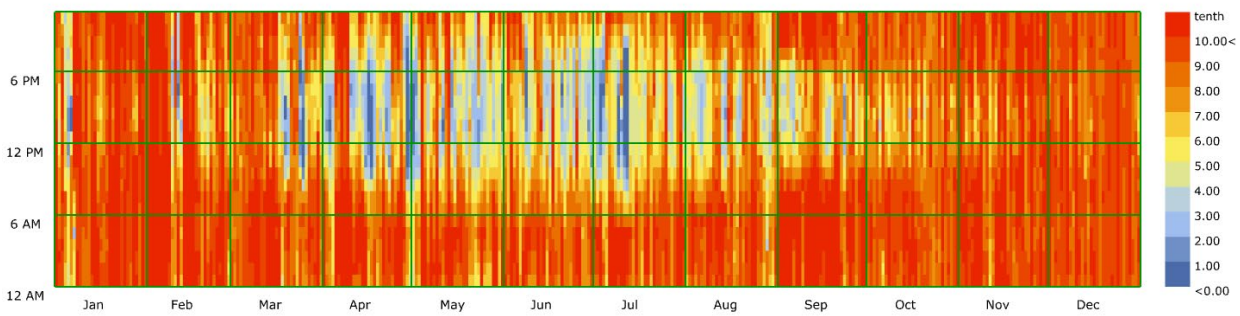

Figure 4. 6 Annual hourly cloud cover with an urban microclimate weather file

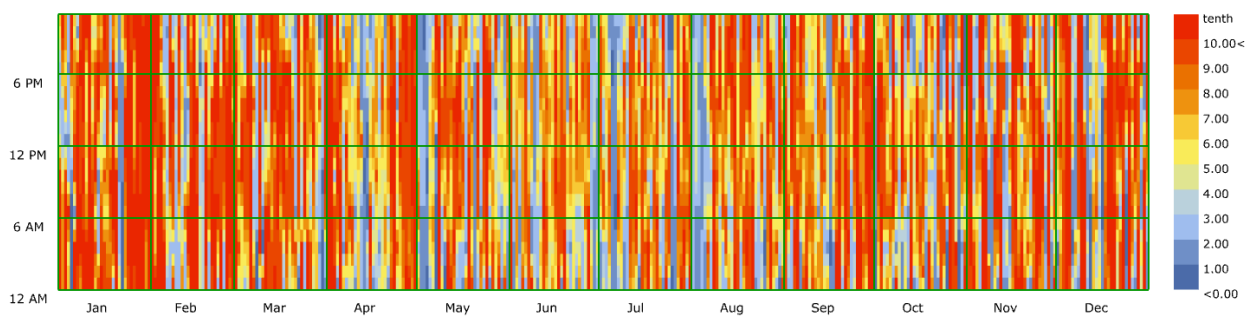

Figure 4. 7 Annual hourly cloud cover with a meso weather file

Global irradiation

Figure 4. 8 shows that, on the extreme coldest day, the global solar radiation of the urban weather file is 134W/m^2 lower than the standard meso^2 (TMY) during the daytime (noon) and similar during the rest of the day. Moreover, on the extreme warmest day, the global solar radiation of the urban weather file is slightly higher than the standard TMY; with only a 21W/m^2 difference see Figure 4. 9.

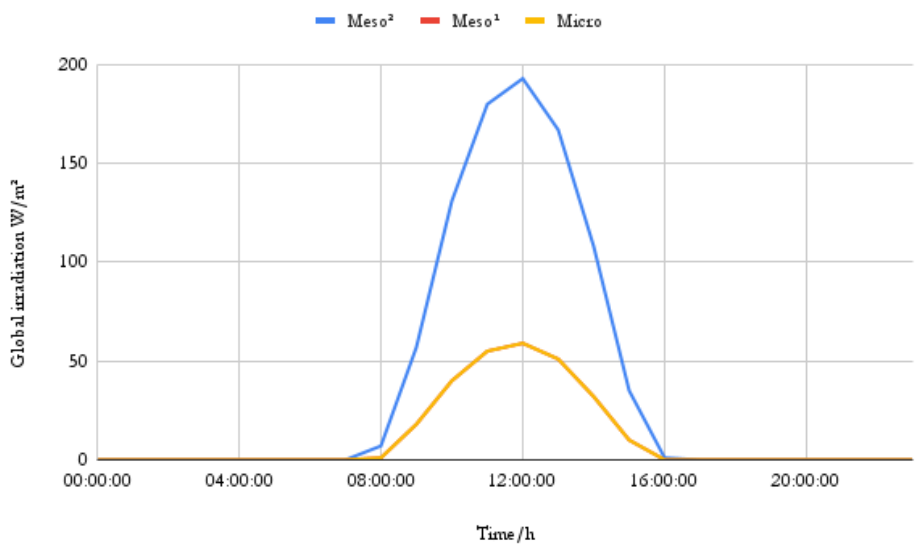

Figure 4. 8 Global solar radiation on January 21

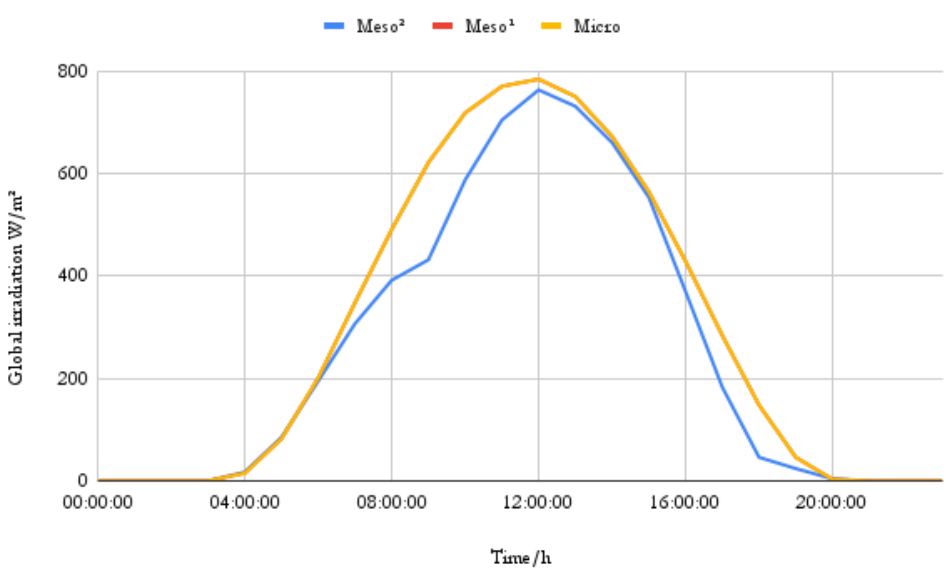

Figure 4. 9 Global solar radiation on July 14

5.1.2. Validation of the urban weather file

The local climatic conditions included urban fabrics within a 400m radius from a target building (M-Huset). Essential climatic variables were compared to those obtained from measured data for validation, considering generated weather file accuracy and reliability.

Air temperature

In Figure 4. 10, the dry-bulb temperature pattern shows stability and is higher than the measured data. On the coldest day, the local air temperature is 15ºC and 4ºC higher at night and daytime. Nevertheless, on the warmest day, the local air temperature is 3ºC and 0.4ºC higher than the measured data.

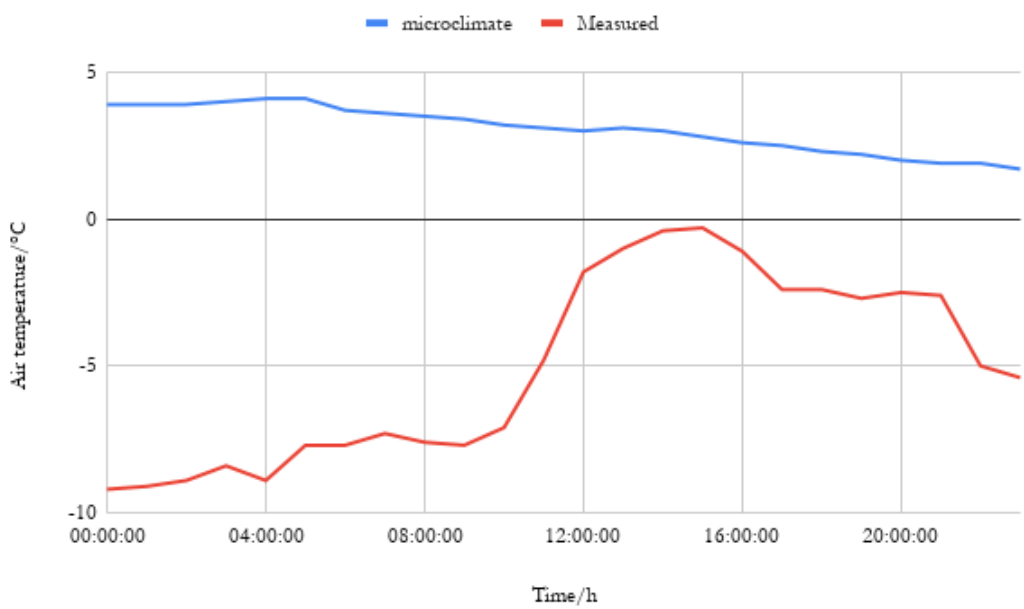

Figure 4. 10 Compared Air temperature on January 21

However, the variations or air temperature could be because of many reasons, like vegetation cover that reduces the air temperature through evapotranspiration and shading. In addition, the procedure of monitoring could affect the measured data.

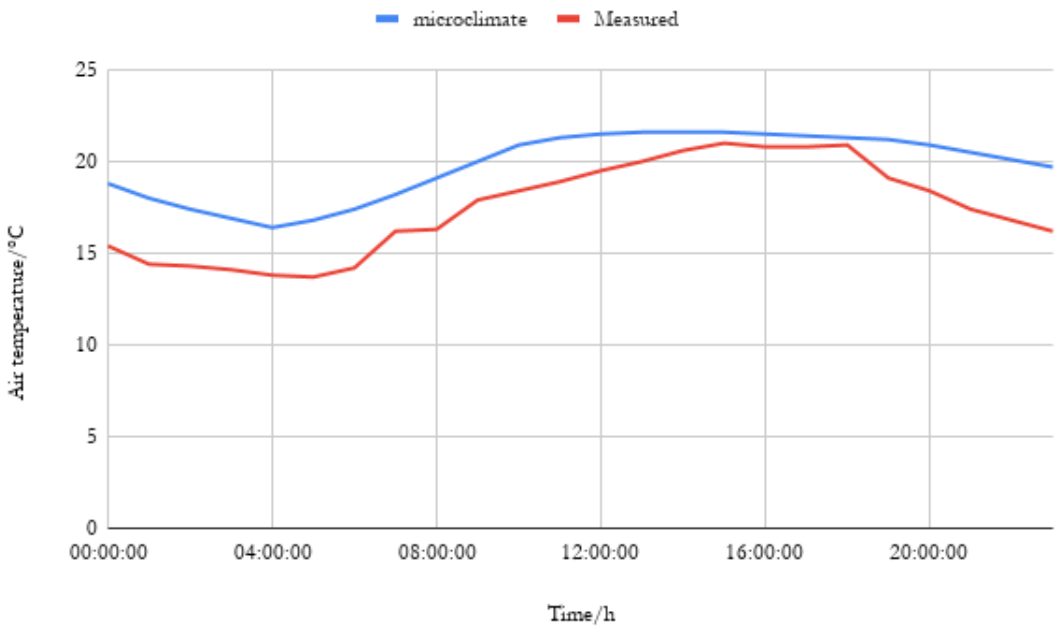

Figure 4. 11 Compared Air temperature on July 14

Wind Speed

The wind appears to be limited and dominant in the NW direction because of the blocking effects of nearby buildings and trees. More clarification figures can be found in Appendix **B.**

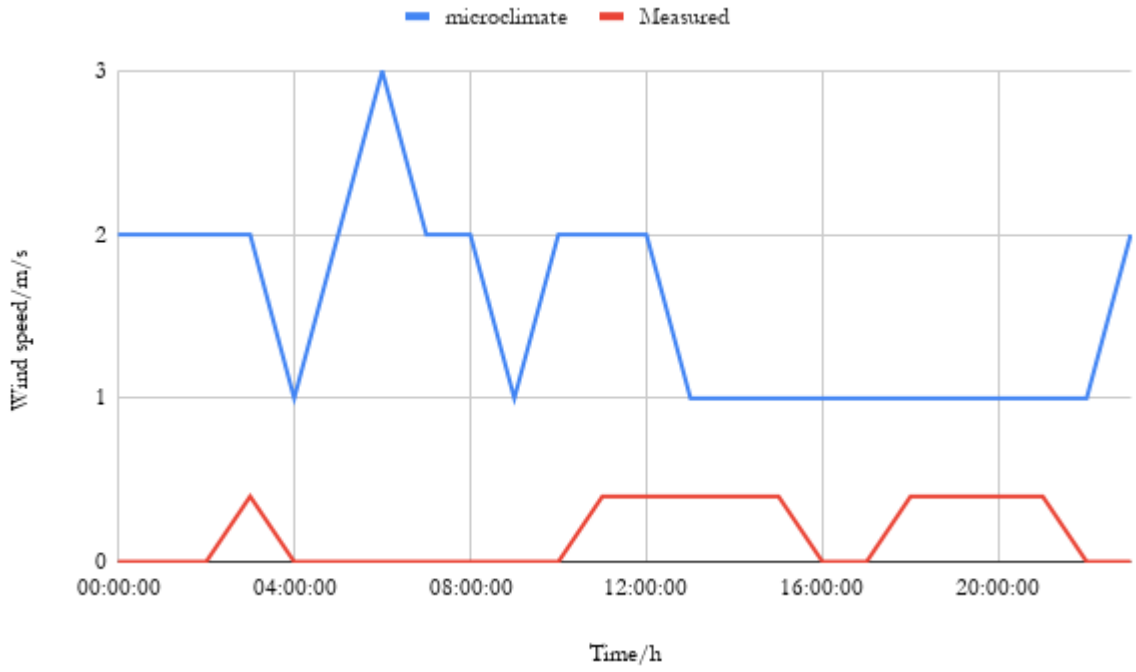

Figure 4. 12-Compared Wind Speed on January 21

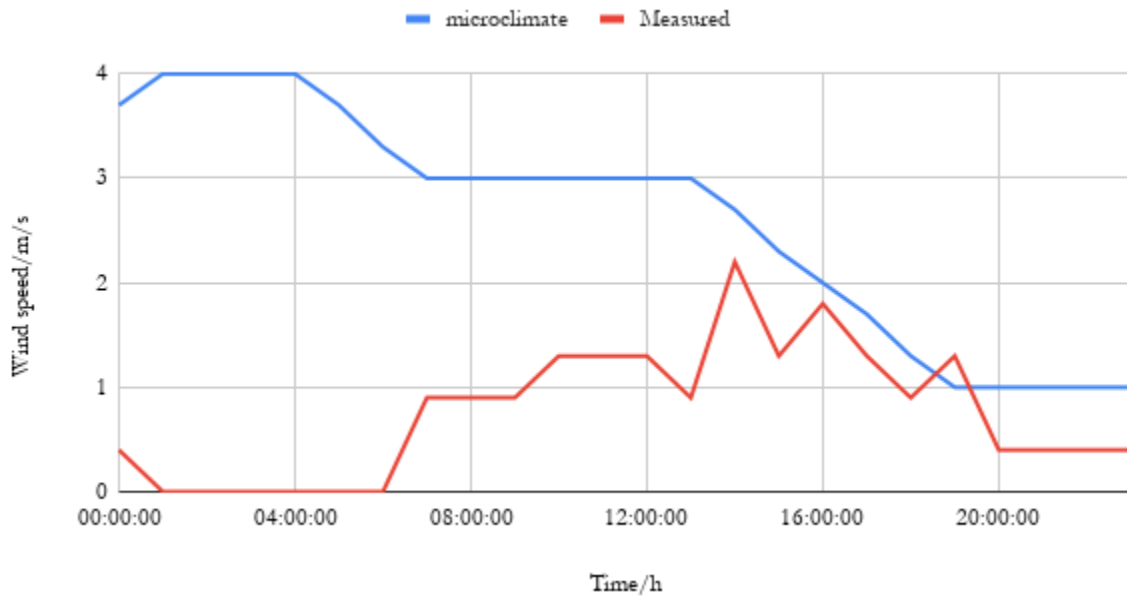

Figure 4. 13-Compared Wind Speed on July 14

Global solar radiation

A similar pattern is observed when the microclimate weather file simulated global solar radiance is less than the onsite-measured data.; however, the compact sensor weather station that was used to measure weather data on-site is considered to be highly accurate than the simulated model except for the calibration discrepancies.

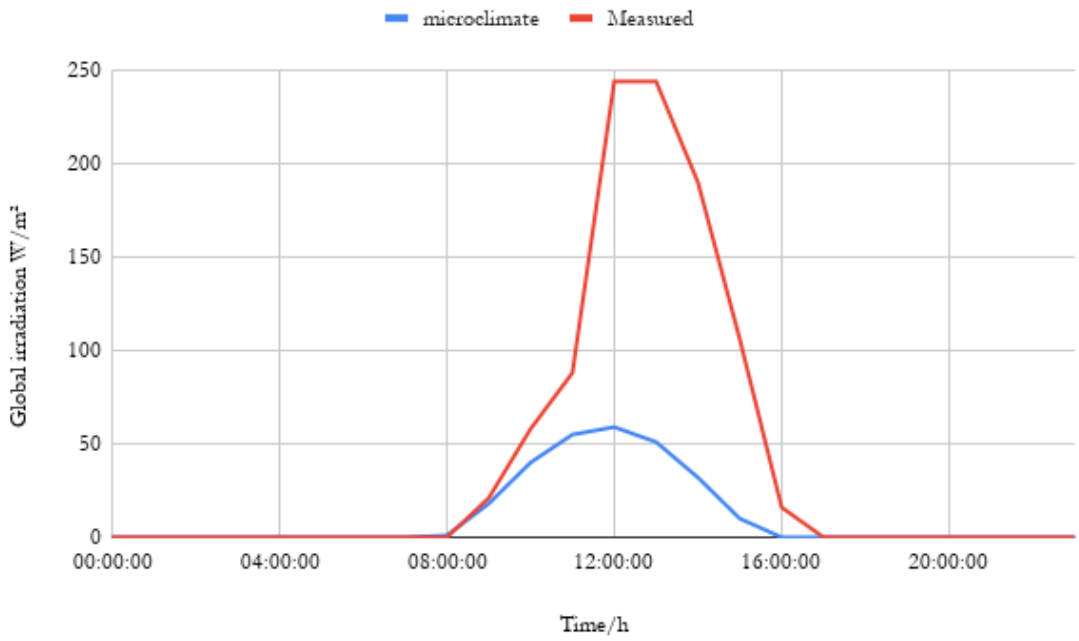

Figure 4. 14-Compared Global solar radiation on January 21,

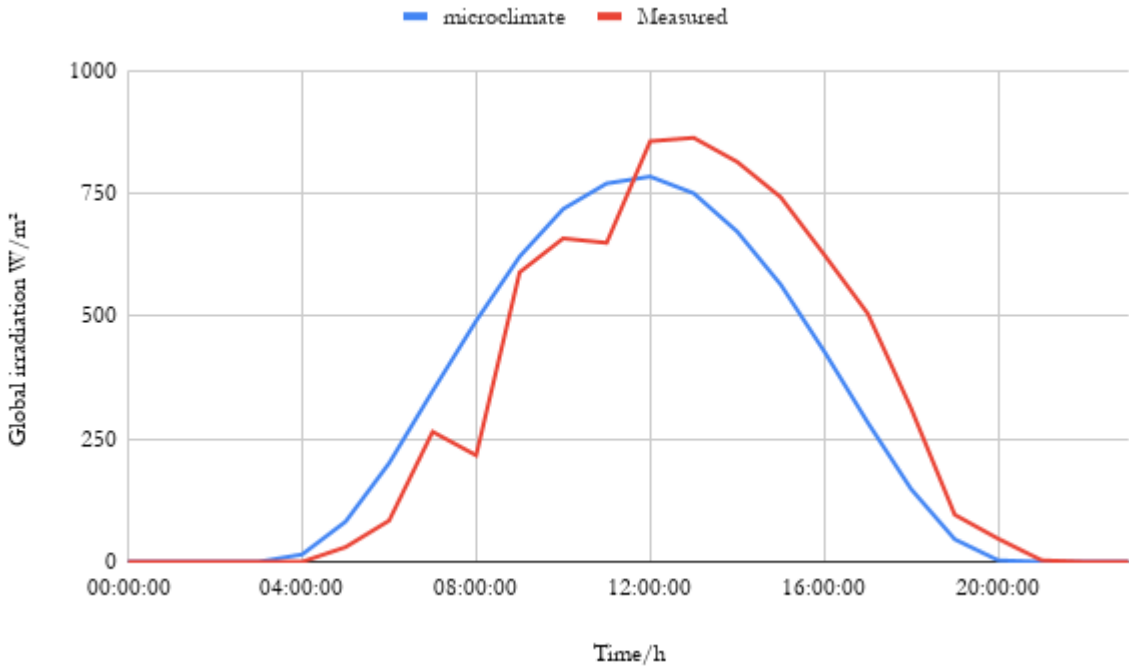

Figure 4. 15-Compared Global solar radiation on July 14,

5.2. Building Energy Simulation (BES)

The building energy demands were simulated in grasshopper using the standard weather files from weather stations and the urban microclimate file. Weather inputs obtained from the urban microclimate weather files were validated before using them as inputs in the building energy simulation to ensure the accuracy and reliability of the BES outputs.

5.2.1. Comparison of the energy demands for each weather case

The compassion-based monthly energy use for heating and cooling was measured in kWh for the entire target building. Figure 4. 16 has June as the peak month with the highest cooling demands for all-weather files. However, the urban microclimate file was 1464.2kWh higher than the Meso (Malmo) weather file, which is about 2.57% higher. Compared to the Macro (DNK) weather file, the microclimate weather file yielded 5130 kWh, a 9.62% increase in the cooling demand in the summertime. Appendix C shows the increment when weighed in the heated floor area.

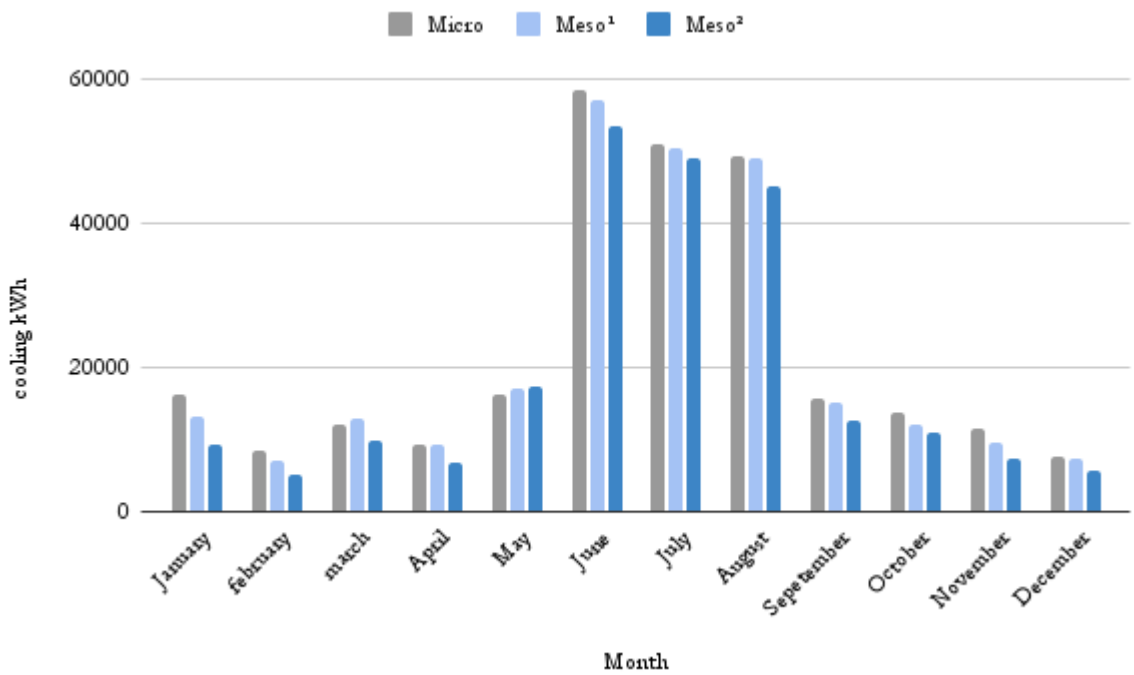

Figure 4. 16-Compared Cooling energy use for each weather case

Moreover, some slight differences were evident in the heating demand measure from all the selected weather files. The urban microclimate weather file has lower heating demands all year round. Figure 4. 17 shows a 1.92% and 2.07% decrease in the heating demand in January with the urban microclimate file compared to the standard files. However, a relatively stable decrease in heating demand with the urban microclimate files is evident throughout the year.

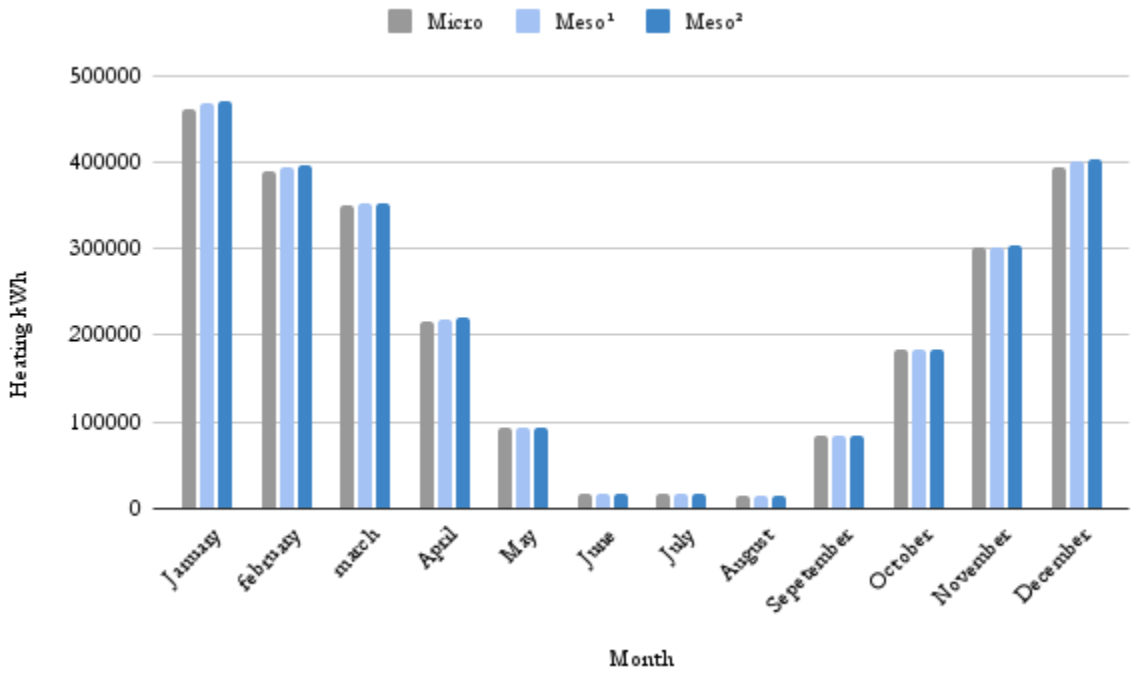

Figure 4. 17-Compared heating energy use for each weather case

5.2.2. Energy Use on Extreme days

Figure 4. 18 shows on both the extreme cold and warm days, the impact of urban microclimate is observed with lower heating and higher cooling demands as compared to the standard weather file at mesoscale.

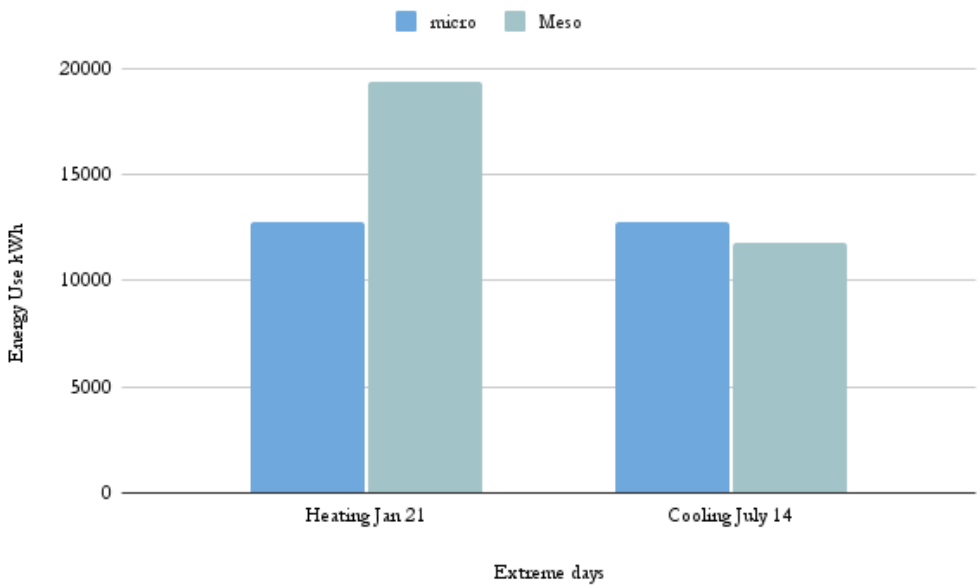

Figure 4. 18 Energy use on extreme weather days

5.2.3. Validation of the urban weather file performance on BES

Ensuring the accuracy and liability of the BES outputs, both the cooling and heating energy demands (ED) were compared with the actual measure ED data received from Akademiska Hus. Received data were measure in kWh/m^2/year for every month; hence, the comparison followed the same format.

During the coldest months (January), simulated heating energy use was only 11314kWh, which is about a 2.4% decrease. The same appears in December and February, where the simulated data is 2.08% less than the actual measured heating energy use of the target building (M huset). Moreover, in the summertime, the simulated results were 2.93% less than the actual measured cooling demands of the target building.

This results pattern outlines the fact that there is an increase in the cooling demands and decreases in the heating demands when accounting for the urban microclimate conditions. However, to see the overall performance, the variation of percentage was prepared to see Appendix D

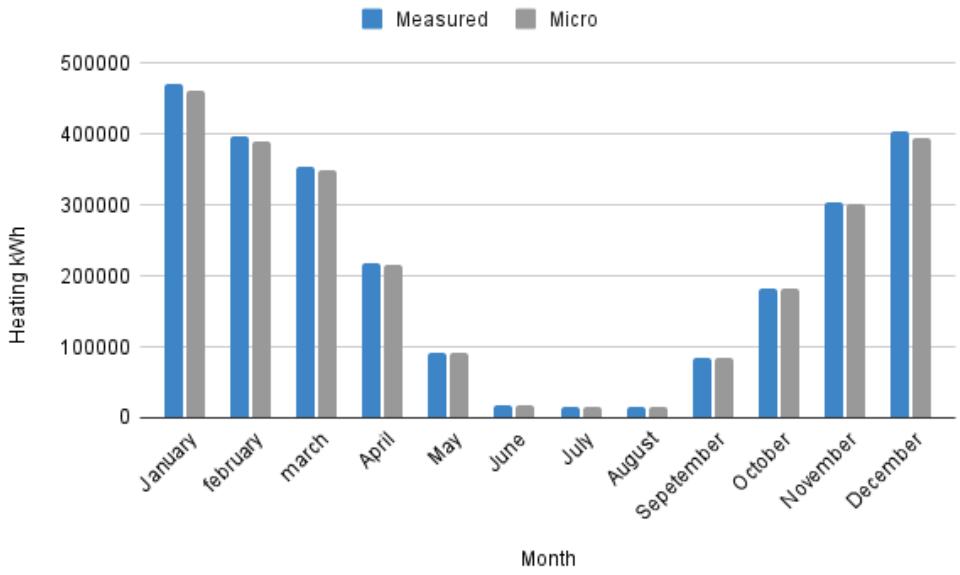

Figure 4. 19-Heating energy consumption between urban weather file and measured data.

However, there is still a slight, considerable difference between the micro-simulated and the measured heating and cooling demands of the case building, and this raised potential research questions regarding what could be causing these apparent differences.

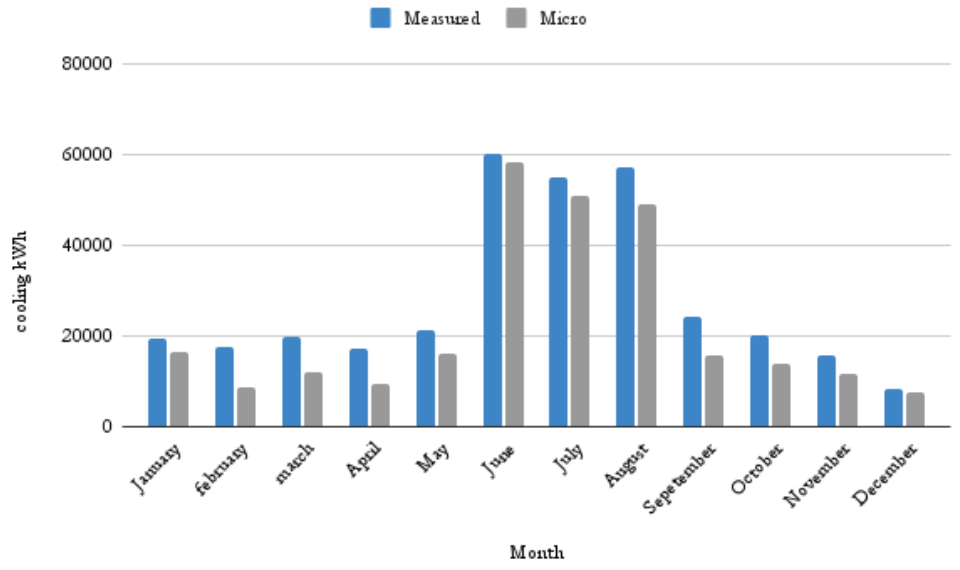

Figure 4. 20-Cooling energy consumption between urban weather file and measured data.

5.3. Solar energy simulations

This section would cover the solar energy simulations outputs. First, annual irradiation analysis followed by a tilt parametric study and simulations results of the electricity produced by PV panels with different with the selected weather files. The simulation outputs accounting for the microclimatic effects would be weighed against the received solar cells monthly production. Additionally, a comparison between the monitored electricity consumption and production by newly modelled PV modules accounting for the UHI effect.

5.3.1. Solar access and irradiance analysis

The annual solar irradiance simulations performed on the target building's roof surfaces show that most parts of the building's roof surfaces met the least amount of threshold amount of annual solar irradiance, as seen in Figure 4. 21.

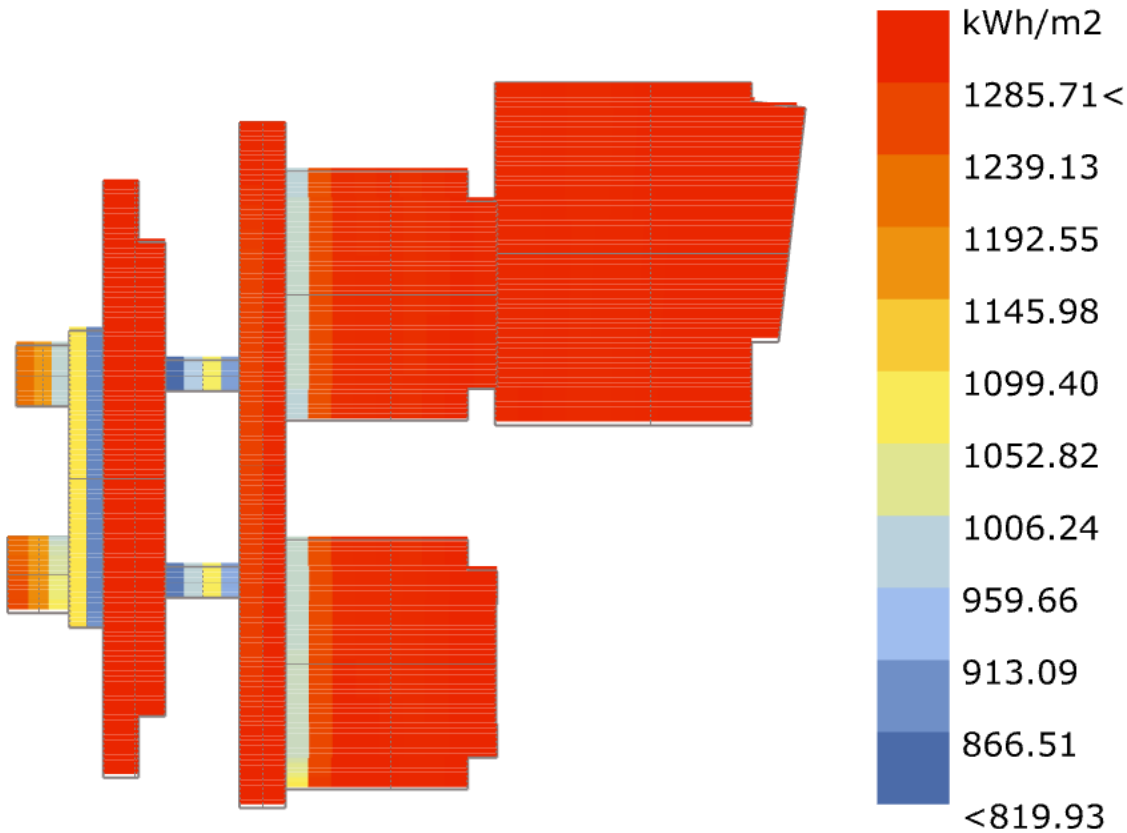

Figure 4. 21 Annual irradiance map of M building

5.3.2. Tilt study

Figure 4. 22, a parametric tilt study, shows that the PV panel would yield an optimum amount of electricity if inclined at 25° to 40° facing south.

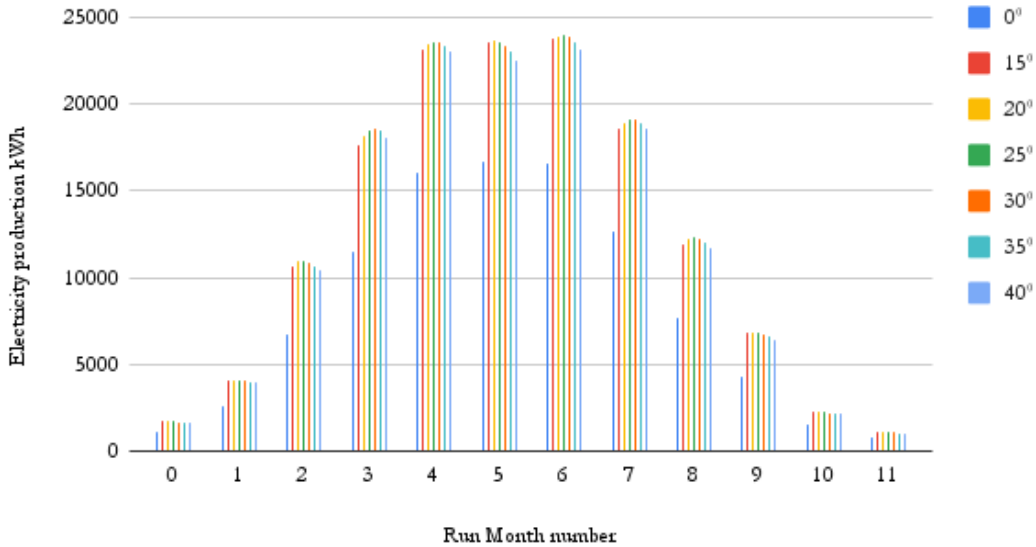

Figure 4. 22 Tilt study

5.3.3. Electricity production with PV cells

A parametric study shows that the PV cells produced more electricity with the microclimate file than the standard weather file and the existing PV cells from optimized tilt, azimuth and potential surface area. With the microclimate file, the PV cells had maximum production all year round, with July as the highest month in production see Figure 4. 23.

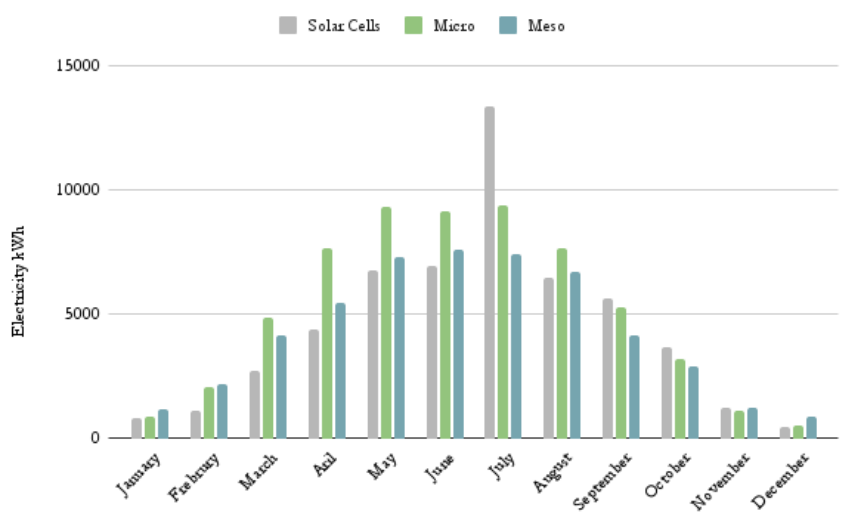

Figure 4. 23 Comparison of PV cells Electricity production

6. Discussion

This study shows that the use of weather files from weather stations located in rural areas in our BES can both underestimate and overestimate the weather impacts on both the coldest and warmest days, respectively.

6.1. Air temperature

This study indicates that local temperatures in urban areas are higher than those measured by the weather stations in rural areas. This is the trapped radiation due to materials used, low convective heat transfer due to wind-blocking and lack of enough green space that provide shading and cooling. Additionally, the exhaust from HVAC systems and traffic as part of the anthropogenic activities highly contribute to the rising urban temperatures. This study shows a difference of 1ºC between urban microclimate weather and standard weather files in the coldest month. However, in July, a microclimate air temperature differs by 2ºC and 4ºC from Malmo and DNK weather files.

6.2. Wind speed

The difference in the wind velocity in both the extreme cold and warm day is because of the blocking of the prevailing winds in the LTH campus where the microclimate conditions were generated; and however, for the DNK weather file, the wind speed is higher due to the geographical location the fact that the ocean surrounds the airport. Additionally, the observed decreasing wind speed during daytime suggests the evident influence of the urban elements such as buildings and trees that lower the wind velocity in the LTH Campus. The decreased wind speeds lead to increased ventilation rates in the simulation and the building systems for air dehumidification, which results in a rise in the cooling energy demands.

6.3. Global Radiation

Since global solar radiation (GR) causes the rise in temperatures, and this study shows that the solar radiation was high with the standard TMY, this raised concern for the importance of considering the impacts of the microclimate conditions of a particular context. This pattern could be because of the clouds cover and shading effect of the surroundings and urban landscaping on the location where the weather file data were generated.

6.4. Accuracy of the wind and global solar radiation data

Most of the commonly available simulation tools and the traditional weather stations do not include the wind and global solar radiation effects in the algorism hence this could lead to less reliability of the outputs. However, more advanced tools coupling advanced knowledge such as computational fluids mechanics (CFD) are recommended.

However, the observed difference between the simulated variables of the urban microclimate and measured data could be because of a compact weather-tracking device that recorded measured data. Most of these devices record the data using sensors that either difficult to customize to fit the research needs or must be calibrated in a short period, usually 1.5 years. This could lead to a lack of discontinuity and inaccuracy of the data collected. However, the case is different for the standard weather stations in airports, and these come with flexibility for the upgrade of the technology as they record data over a long period.

Moreover, the UWG engine accounts for all possible city features such as urban morphology, geometry, and surface materials coupled with the actual EPW from the weather station. This gives more advantages to the urban weather files generated than the measured data. Therefore, this study finds the difference between simulated microclimate variables and the measured variables to be convenient due to the discussed reasons.

6.5. Energy Use

This study suggests an evident advantage of the UHI during winter, where the heating demands with the micro file decrease by 1.92% and 2.07% compared to the standard weather files. However, the same cannot be said in summer, during which the study shows that the cooling energy demands increase by 2.57% and 9.67% compared to the Malmo and DNK weather files, respectively.

Moreover, this study shows different encounters where the energy demands from the building energy simulation are less than the measured data received. During summer, simulated cooling demands were 2.93% less than that of the measured cooling demands indicating the impacts of higher temperatures and a very slight difference because of anthropogenic factors. However, in winter, simulated heating was 2.4% for January and 2.08% for the rest of the cold months, less than the actual heating measure data received. This study suggests that this slight difference could

be because of many reasons, including user behaviour, assumptions made, and other anthropogenic activities.

Therefore, the difference between using airport weather data and local climate data is evident; suggesting that evaluating the influences of the microclimate conditions on building energy simulations models is indispensable. Since airports are located in less dense areas, yet far from case areas, many things could be leading to the variations.

6.6. Solar Energy

Moreover, regarding potentiality and electricity generation on-site to accommodate the current electricity demand and be more sustainable, a promising energy source such as solar energy is essential. From the PV cells, a parametric study performed. Still, it was hard to accommodate the case building (M huset) demands as an auxiliary system. However, this study recommends covering the summertime energy consumptions, and this would require a more extensive field than the existing solar cells, which would be about 10 times bigger than the existing system with 191kWp see Appendix D.

7. Limitations

This study has rather issues that hinder the absolute accomplishment of the aim and goals. These issues can be categorized into two,

Case related.

1. Insufficient information regarding the case building, construction properties, occupancy schedule, HVAC systems
2. Energy calculations and setpoints were mainly based on sound assumptions; this may cause a gap between the conclusive BES outputs and the measured data.
3. Discrepancies caused by the weather station on-site as for received data did not cover a full year measurement.

Research-related

This study couples urban microclimate and building energy simulation models; however, it did not experiment on the following factors.

1. Vegetation cover as one of the vital influence on climatic parameters was not studied.
2. Building forms.
3. Façade materials.

8. Conclusion

In this study, the impact of three different weather files representing the level of variations of climatic conditions on the energy performance is evaluated. In this regard, the study coupled a model for the urban microclimate and building energy simulation. On-site measurements were used to validate both models, and this helped in understanding and evaluating the impacts of urban microclimatic conditions on the accuracy of the building energy simulations models.

The main findings of this study confirm that urban areas are characterized by higher local air temperatures and low wind speeds boundary conditions compared to rural areas. However, even a considerable variation in these vital climatic variables could cause impacts in the accuracy of the buildings energy simulations outputs.

As expected, when measured against standard weather files, the microclimate weather file predicted a cooling demand increase of 2.57% and 9.67%, respectively, during the warmest month due to local temperatures. At the same time, the predicted heating demand decreased by 1.92% and 2.07%, respectively, during the coldest month. However, the simulated demands were slightly lower than the measure data. This study concludes this could be due to assumptions for the simulations inputs and user behaviour for most human activities such as industrial activities. Vehicles all add up to the increased level of local temperatures and affect energy performance. However, this study had the luxury to identify the possible factors that could cause these variations in the local climatic conditions and building energy performance; some of these are listed below;

- Building materials such as concrete absorbs and re-emits heat; glass façade reflects solar radiations, respectively can modify the outdoor air temperatures.
- Evaporative surfaces such as vegetation and water bodies help reduce the temperatures and solar radiation effects through evapotranspiration or evaporative heat transfer.
- Building forms, density, and orientations can lead to wind sheltering, low wind speeds, and low convective heat transfer.
- HVAC exhaust and traffic.
- Anthropogenic activities.

All listed factors could lead to modification of the urban weather conditions that affect the energy performance of the buildings.

Moreover, this study shows that the entire LTH campus has a high solar energy potential to use solar PV for electricity production regardless of the type of weather file, so an extensive study on the PV technology and efficiency is recommended.

Hence, this study concludes that accounting for the urban microclimate conditions causes a significant variation in the overall energy performance of the buildings by increasing the cooling demands and degreasing the heating demand. Therefore, this study recommends microclimate conditions to be considered in early undertakes when accounting for the accuracy and liability of the BES models.

9. Further Research

The study dealt with only the comparative analysis of significant climatic variables, some other studies based on buildings forms, vegetation cover and building materials. However, a collaborative study that includes all the named subjects would be more efficient in predicting urban climatic conditions and their impacts on the building energy simulations accounting for accuracy.

Additionally, quantifying the impacts of considering urban microclimate conditions from the economic and environmental perspective would be relevant and comprehensible to the world.

10.General Summary

Today's city is becoming overpopulated, which causes an increase in densification and compactness of the city buildings to accommodate the rising population. However, these urban fabrics and anthropogenic events have caused the formation of a new phenomenon called UHI. Cities experience higher temperatures compared to rural areas due to the modified climatic conditions. Additionally, due to the growth of the building sector, the amount of energy consumed by buildings primarily for space cooling and heating purposes is said to have reached about 48% of the world's total energy consumption. Countries with frigid weather and hot weather conditions are keen to investigate and understand these conditions as they affect the building energy sector. Hence understanding the impacts of the urban microclimate conditions becomes entirely essential.

Following up on the UHI trend, it is evident that investigating urban microclimate is very important. The objective of this study is to evaluate the impacts of considering urban microclimate conditions in the building energy simulations when accounting for the accuracy and reliability of the outputs based on the LTH campus of Lund University Sweden. Therefore, this is done by investigating the variations of important climatic parameters such as air bulb temperature, wind speed and global solar radiation of the weather files, DNK representing macro climatic conditions, Malmo representing meso climatic conditions, and a newly generated weather file representing urban microclimatic conditions. Then, investigation of the target building m- building energy performance when its BES model has used all the weather files as inputs. All the outputs weighed against actual monitored data to see the magnitude of microclimate impacts on the accuracy of the BES model.

The whole of LTH campus buildings are marked to have solar energy potential due to the similarities of their building forms; hence, most building surfaces, mainly roofs, receive a suitable amount of solar radiation. In M huset, a large field of PV models or a system over 4 times bigger than the existing one at a fixed angle of 40o is recommended to cover the electricity consumption in summer.

11.References

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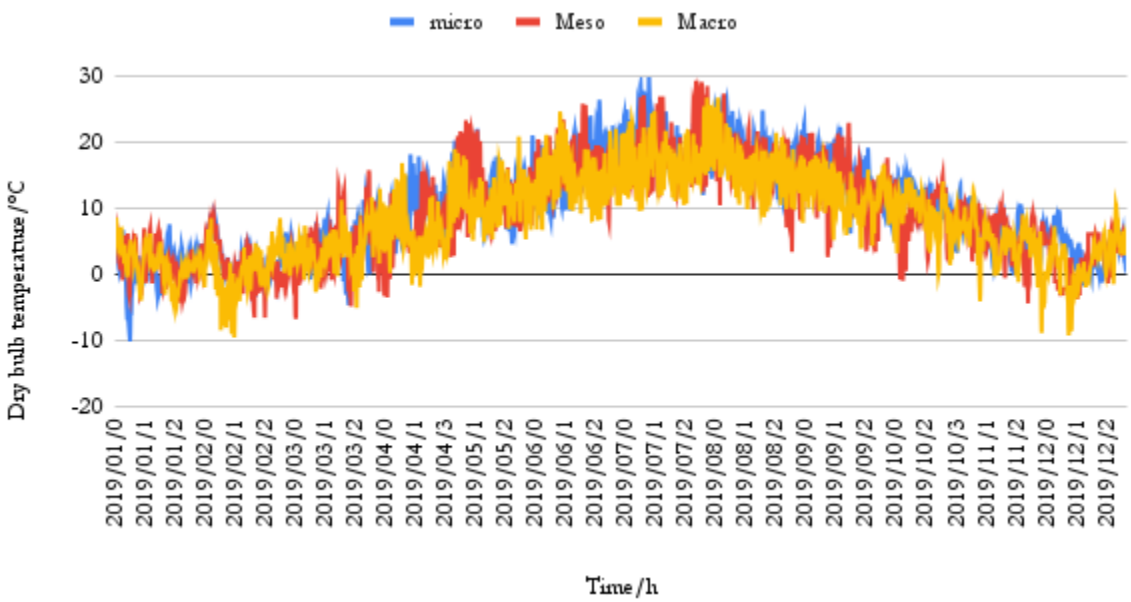
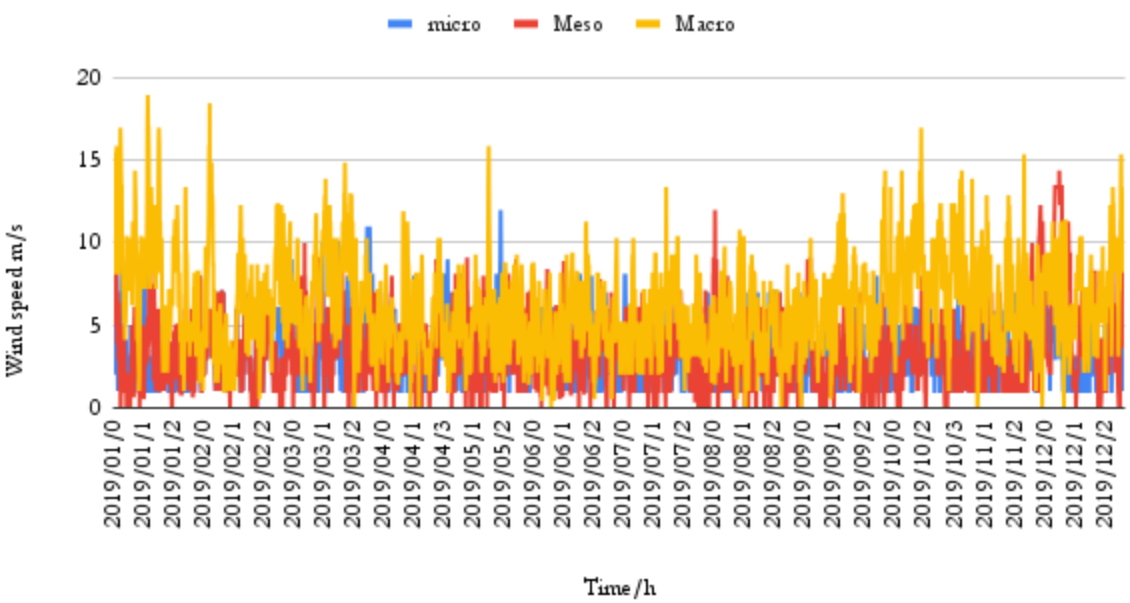
Appendices

Appendix A

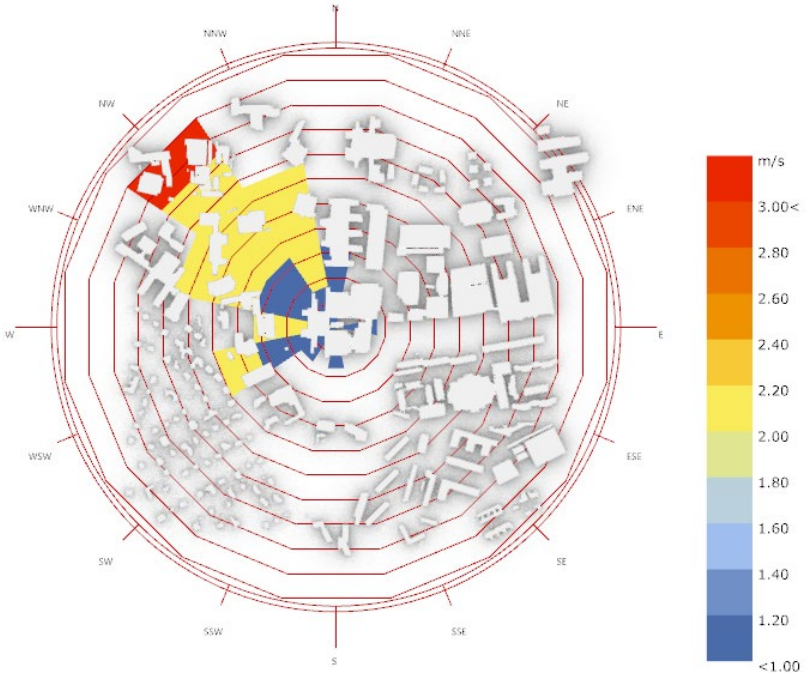
Annual hourly data



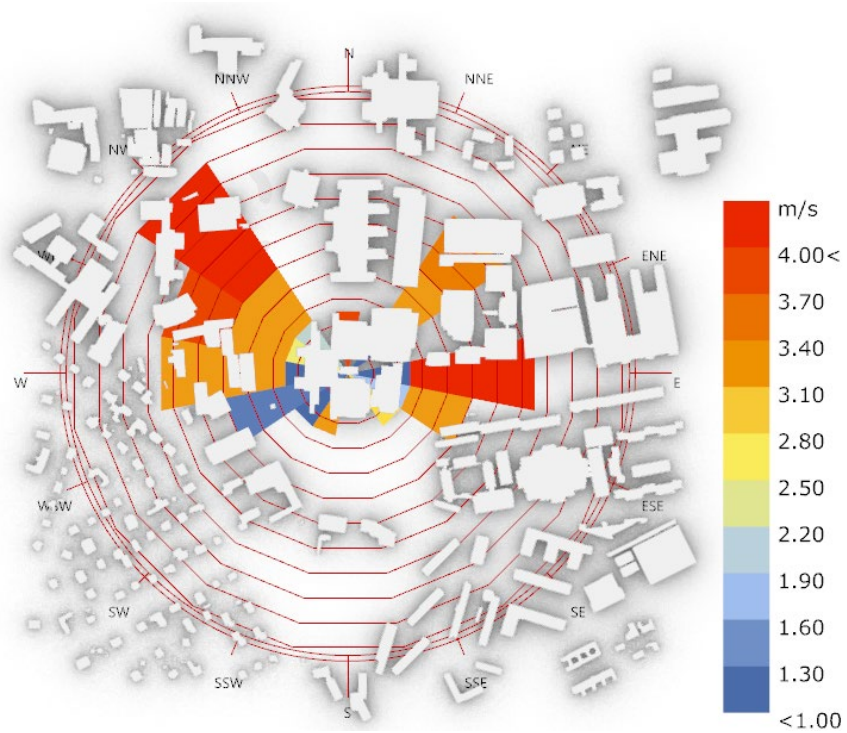


Appendix B

The wind rose for January 21

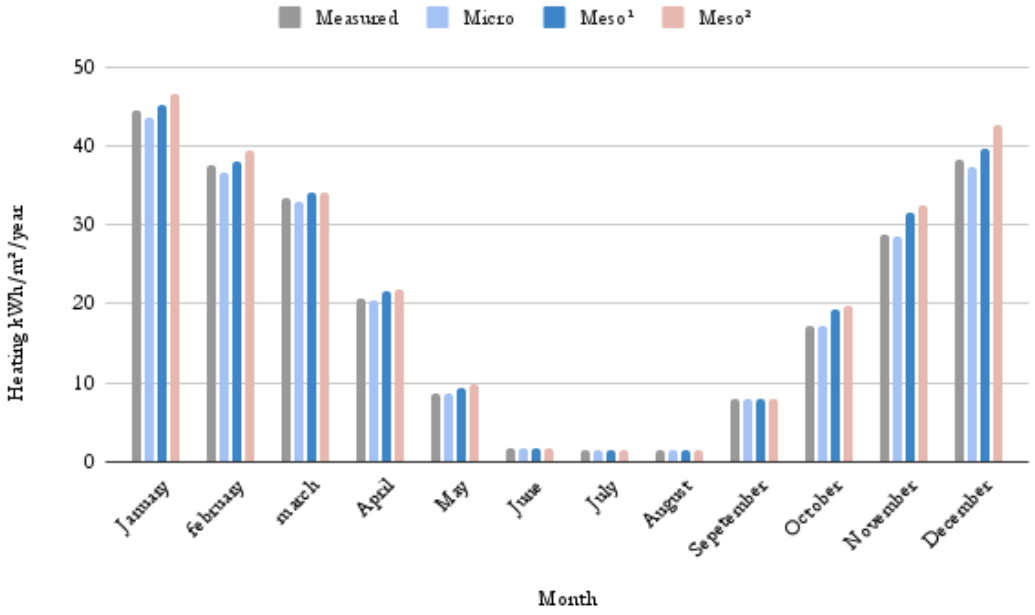


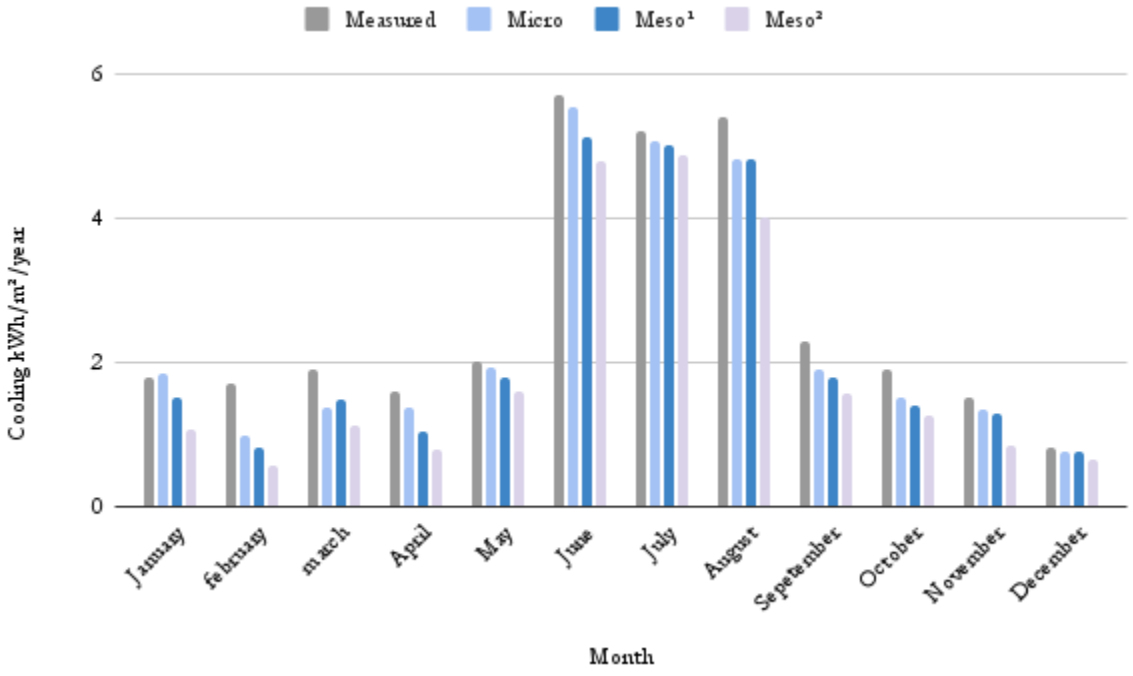
The wind rose for July 14



Appendix C

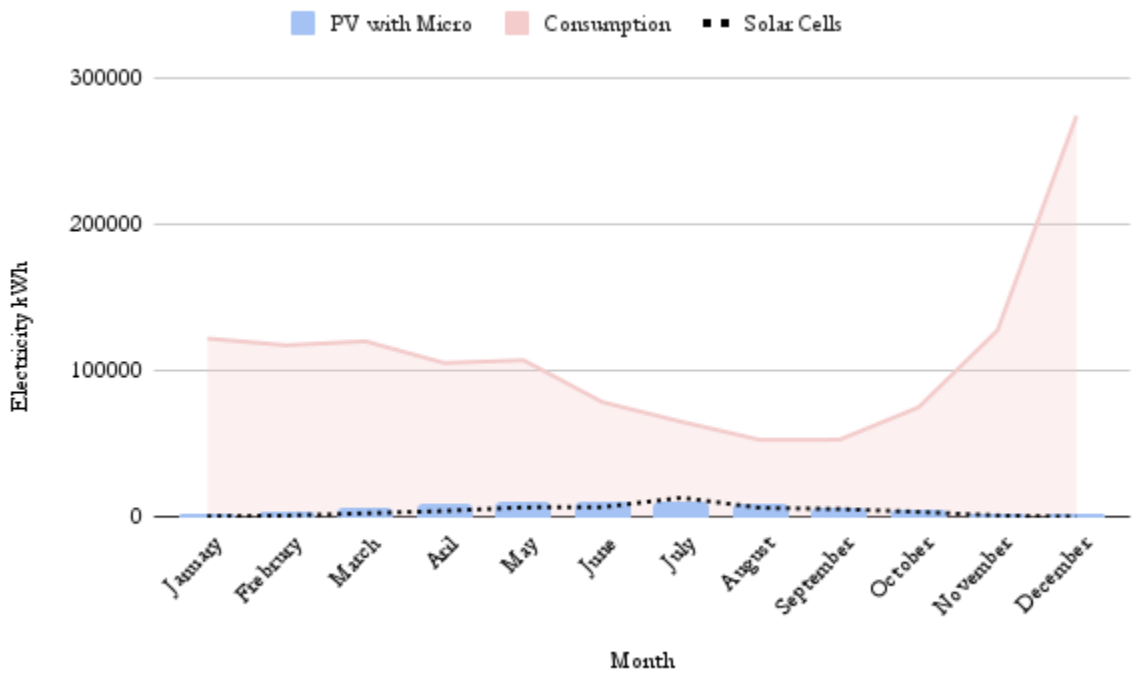
Energy use weighed against GFA





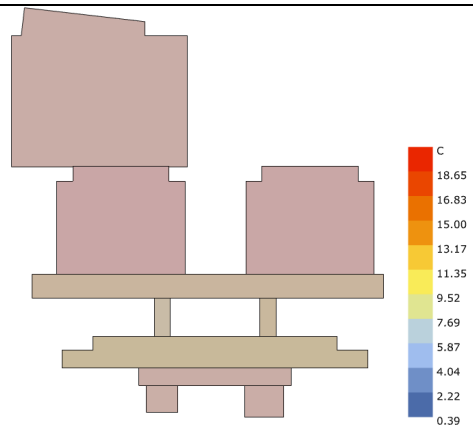
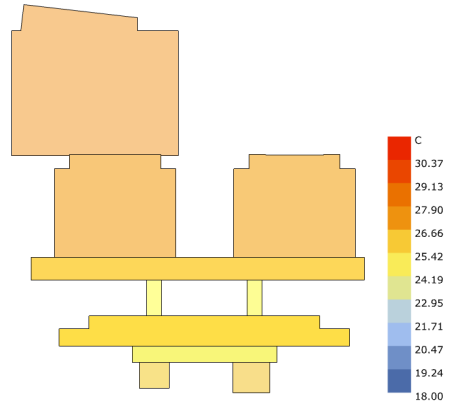
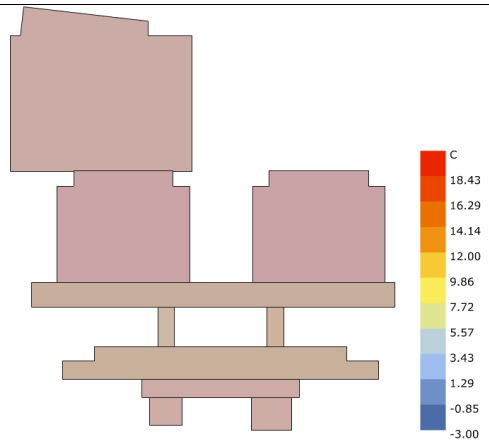
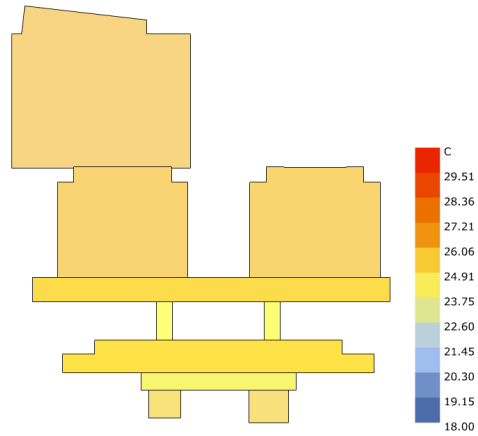
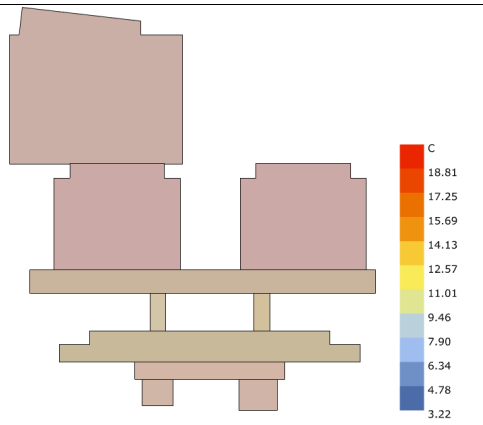
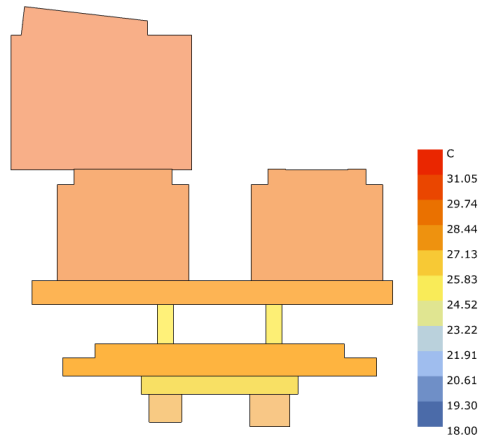
Appendix D

Electricity consumption of the target building M-hus weighed against electricity produced by the existing solar cells and modelled PV panels (with the UHI effect)



Appendix E

Surface temperatures of the target building on extreme days.

	January 21	July 14
Meso		
Macro		
Micro		

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