MASTER THESIS

The Representation of Urban Climate for Effective Building Energy Performance Simulation

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KURZFASSUNG

Im Moment berücksichtigen thermische Gebäude Simulationen in den meisten Fällen nicht die lokalen mikroklimatischen Bedingungen. Das hat vor allem damit zu tun, dass lokale Wetteraufzeichnungen nicht verfügbar sind oder aber nicht geeignet um spezifische, lokale Mikroklimate nachzumodellieren. Diese Master-These fokussiert auf die Bewertung eines jüngst entwickelten Modells zur Generation von lokal angepassten Mikroklima-Daten anhand von Daten von Referenzwetterstationen, welche im Stande sind die jeweiligen standortspezifischen Mikroklima-Daten nachzubilden. Die Unterschiede zwischen den mikroklimatischen Bedingungen bei der jeweiligen (zumeist urbanen) Location (Gebäude bzw. Site) und den jeweiligen Standorten von Wetterstationen (oftmals beispielsweise bei Airports außerhalb der Stadt) sind nur wenig erforscht. Solche Unterschiede bestehen beispielsweise bei den Temperatureverläufen, der Feuchtigkeit, Windgeschwindigkeit und –Richtung. Diese Variablen sind aber zumeist die Haupteinflussfaktoren auf Wärme- und Stofftransferprozesse in bzw. an Gebäuden. In dieser Arbeit wurde folgendermaßen vorgegangen:

Zunächst wurden die mikroklimatischen Bedingungen für eine Reihe von Locations in Wien erhoben bzw. analysiert. Das Werkzeug Urban Weather Generator (UWG) wurde eingesetzt um stündliche Temperature und Feuchtigkeitsdaten aus einer ländlich gelegenen Wetterstation zu verwenden und für die städtischen Locations zu adaptieren. Messdaten welche vor Ort an den städtischen Locations erhoben wurden, wurden verwendet um diese generierten Daten zu validieren. Anschließend wurden sowohl die gemessenen wie auch die simulierten Daten verwendet um Gebäudesimulationen von zwei typischen Bauwerken (einem Wohngebäude, so wie einem Bürogebäude) durchzufüren. Die Ergebnisse dieser Simulationsbemühungen wurden einander gegenübergestellt. Darüber hinaus wurden Simulationen mit standardisierten Wetterdaten für Wien bzw. den Wetterdaten der ländlich gelegenen Wetterstation angestellt.

Die Ergebnisse dieser Bemühungen zeigen, dass die Verwendung von standardisierten Wetterdaten im Rahmen von thermischen Gebäudesimulationen zum Teil zu recht unrealistischen Ergebnissen betreffend Energiekennzahlen führen können. Diese standardisierten Wetterdaten können zum Einen nicht das zutreffende Mikroklima in jedem Teil einer urbanen Agglomeration beschreiben und zum anderen beruhen diese Daten oft auf historischen Langzeitmessungen, welche aktuelle Veränderungen in den Mikroklimaten bzw. in der Großklimasituation nicht berücksichtigen. Deshalb sollten neue Wetterdaten generiert werden, welche das

aktuelle Mikroklima anhand aktueller Messdaten besser beschreiben. Messdaten, die nicht im urbanen Umfeld gesammelt werden, wie z.B. bei Flughäfen vor den Toren einer Stadt, bilden die signifikanten Unterschiede zwischen ländlichen und städtischen Umgebungen jedoch nicht ab. Der UWG kann dazu verwendet werden, diese Unterschiede über Modifikation der Wetterdaten auszugleichen. Es versteht sich von selbst, dass solche Werkzeuge – welche zur Generation von urbanen Wettermodellen verwendet werden können – einen Nutzen für Gebäudesimulationszwecke haben.

Keywords (deutsch): Modellierung von urbanem Mikroklima, Mikroklima-Simulation, Wetterdatengeneratoren, Gebäudesimulation, Wetterdaten

ABSTRACT

Currently, simulations efforts of thermal building performance regularly do not consider the location-dependent microclimatic conditions. This is majorly due to unavailability of monitored data from metrological weather stations or the failure to model specific location microclimates. This contribution focuses on assessing a recently developed model for generating urban weather files from a reference (weather) station that reflects the corresponding microclimate of a location. The differences between building site location and measurement station located at a distance from the building in rural areas such as airports are scarcely researched. Such variations can pertain to temperature, humidity, wind speed and wind direction, which are prime driving variables for heat and mass transfer processes in a building. First, microclimatic circumstances for several locations within the city of Vienna have been analyzed. The Urban Weather Generator (UWG) has been applied to estimate the hourly urban air temperature and humidity using weather data from a rural weather station and accounting for the reciprocal interactions between buildings and the urban climate. The urban measured data has been used to validate the simulated urban data. The measured and modeled weather data have been used as boundary conditions, and both a typical residential and an office building are subjected to thermal performance simulations. For all urban locations, the resulting performance indicators were then compared. The results have been further compared to the outcomes of the simulations that used simultaneously measured rural weather and standardized weather files commonly used for Vienna. The results suggest that the use of standardized weather files for building performance simulation can result in rather unrealistic energy demand estimations. This is due to the fact that this data does not describe the actual climate in each part of the city and is typically based on a historical long- term measurements. Therefore, new weather files should be created to reflect recent local climate change using more recent measurements. However, measurements from a reference station located outside of the urban area such as airports are neglecting the significant differences between rural and urban surroundings. The UWG can reduce this difference between urban and rural heating and cooling demand in urban locations. The results suggest that methods for generating urban weather files from a rural station and that account for the site-specific microclimatic conditions have utility in building performance simulation.

Keywords

Urban climate modeling, microclimate simulations, weather data generators, building performance simulation, weather files.

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CONTENTS

LIST OF ACRONYMS AND ABBREVIATIONS

	General
BPS	Buildings Performance Simulation
CDH	Cooling Degree Hours
CSV	Comma Separated Values
epw	Energy plus Weather
GSR	Global Solar Radiation
HDD	Heating Degree Days
HVAC	Heating, Ventilation and Air Conditioning
MBE	Mean Bias Error
RH	Relative Humidity
AH	Absolute Humidity
RMSR	Root Mean Square Error
TMY	Typical Meteorological Year
TRY	Test Reference Year
U2O	Urban Unit of Obsevation
UBL	Urban Boundary Layer
UCL	Urban Canopy Layer
UHI	Urban Heat Island
UWG	Urban Weather Generator
WMO	World Metrological Organization
XML	Extensible Markup Language
ZAMG	Zentralanstalt für Meteorologie und Geodynamik

	Project Related
AB	Apartment Block
DF	Donaufeld
HW	Hohe Warte
IS	Inere Stadt
OF	Office Building
MB	Mariabrunn
SD	Seibersdorf
ST	Standardized weather file

1 INTRODUCTION

1.1 Overview

Dynamic building energy simulations are becoming increasingly necessary for the analysis of the energy performance of buildings as well as the thermal comfort of occupants in the design and the operation phases (Hensen et al. 2011). Energy simulation programs require climate information to simulate the response of the buildings. Traditional weather data for simulation are hourly based measurements taken at national meteorological stations at a specific location. These data include temperature, humidity, wind speed, wind direction, atmospheric pressure, and solar radiation or cloud cover data. The typical Meteorological Year (TMY) and Test Reference Year (TRY) are typical weather files commonly used for building simulation applications. Those data are readily available from weather stations located at a distance from the building in rural areas such as airports (Wilcox and Marion 2008), not considering the variations of climates between these locations and urban regions such as city centers and dense building sites through the commonly known urban heat island effects (UHI) (Arnfield 2003). The variations are in temperature, humidity, wind speed and wind direction, which are prime driving variables for heat and mass transfer processes in a building. These discrepancies can thus lead to significant inaccuracy in performance simulation results (Hong et al. 2013, Eames et al. 2011, Wang et al. 2005).

This thesis aimed to underline the need to represent the urban microclimate in the weather file when predicting building thermal performance. The observed weather data from different urban locations are structured and analyzed to represent the variation in the urban microclimate in the city of Vienna. The urban weather generator (UWG) developed by (Bueno et al. 2012) is used to calculate the hourly urban air temperature and humidity utilizing weather information from a rural weather station. Subsequently, the measured and modeled weather data of five consecutive years (2010-2014) used for simulation of two representing buildings located in multiple locations in Vienna. The results are further compared to performance indicators resulting from simulations based on simultaneously measured rural weather and standardized weather file commonly used for Vienna to identify discrepancies with regards to the accuracy of predictions of the building´s thermal performance.

1.2 Motivation

The world population is growing and becoming more urban. Urban density is increasing and with it increases urban heat island and the complexity to understand the effect of one building over the other. Building occupants have higher comfort demands, implying the crucial need to analyze their adaptive thermal comfort. The urban microclimate is relevant to people`s health as well as building energy consumption (Harlan and Ruddell 2011, Akbari 2005). For all this, a better understanding of urban climate and proper simulation of the performance of urban buildings become a necessity (Arnfield 2003, Clarke 2001). Despite, concentration has been placed in developing and advancing building simulation capabilities (Wang and Zhai 2016, Crawley et al. 2008). The usage of the same climate representation from the past is continued, a typical historical data derived from hourly measurements at a specific location by the national weather service or meteorological office outside the metropolitan areas (Crawley 2007). In recent years, researches have proved that the microclimate circumstances can differ significantly (Mahdavi et al. 2013). The explanation is the variation in the urban surface's materials, the absence of green areas, the nonexistence of water bodies, the reduction of the wind speeds, and the higher anthropogenic heat production in the metropolitan areas (Wong et al. 2016, Hagen et al. 2014). Several studies (Kiesel et al. 2016), (Wong et al. 2011) and Crawley (2008) studied the significant influence of the adjacent urban morphology on the energy demand of buildings. Thereby, utilizing standardized weather files in the simulation of the thermal performance of buildings causes significant errors (Hong et al. 2013). These considerations represent the main motivation behind the research questions addressed in this thesis: What is the difference in energy demand of buildings simulated by standardized and site-specific weather files? How much can the difference between rural and urban microclimate affect the energy demand of buildings? Is there is a significant reduction of these errors in energy performance prediction when using tools to generate site-specific weather file? This work will point to the weight of the representation of the urban climate in the energy simulation which will result to have more reliable and proper predicted values.

1.3 Background

1.3.1 Overview

Building energy consumption and the indoor environment are derived from several factors. The key factors are the outdoor environment (weather), occupants and auxiliary systems (Hensen 1999). Figure 1-1 presents these factors which cause many energy and mass transfer processes such as:

- conduction through the layers of the building fabric,
- radiation; short-wave solar radiation transmission through glazing and longwave radiation exchange between surfaces of buildings which absorb short solar radiation and emit long-wave infra-red radiation,
- convection follow-on the circulation of air of different temperatures,
- airflow across the building envelope into the building, and within the HVAC systems.
- fluid flow for the plants

The building is a combination of elements and systems with complex relationships. Therefore, computer modeling and simulation is the only way to predict building behavior (Clarke et al. 1999, Augenbroe and Winkelmann 1990). Building simulation software has significantly improved in quality and depth of analysis capability over the past years making it possible to simulate the non-linear interactions of buildings elements and systems (Augenbroe and Hensen 2004).

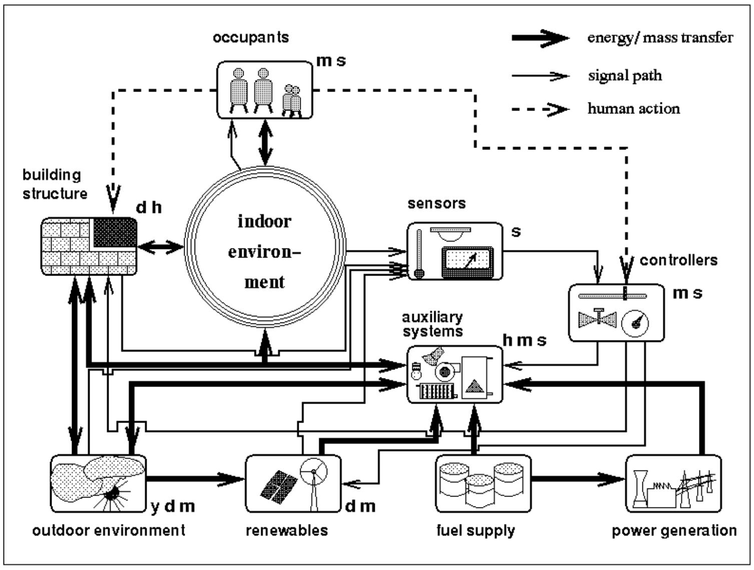

Figure 1-1 The complex interactions between buildings elements and systems (Hensen 1999)

1.3.2 Input to energy simulation programs and uncertainties

Figure 1-2 displays the general flow of information in building performance simulation software. Information such as buildings' geometry, internal loads, operating strategies and schedules, occupants, building systems and climate data are needed to be provided to achieve an accurate prediction of the performance of a building (Maile et al. 2007). Usually, the required information needs to be organized in the form of input files that consist of keywords and data which follow particular structures and formats to be easily shared among major energy simulation programs (Crawley et al. 1999). The reliability of outcomes of building performance simulation relays on the quality of input data, the competence of the simulation engineers and the applied methods in the simulation engine. (Dodoo et al. 2016) state, that the correctness of simulation results significantly varies with the possibility of various assumptions or not life-realistic input data. Due to the importance of this subject, many journal publications have been dedicated to the accuracy in building energy modeling, identifying significant differences between real measurements and simulation output results (Li et al. 2015). On the other hand, other papers seem to prove the opposite, that simulation results do indeed match real-life measurements (Christensen et al. 2015). Optimization methods using collected data have taken place to increase precisions of simulation results, through the calibration of computer simulation models (Raftery et al. 2011).

The proper building simulation considers numerous external factors, which may be sources of uncertainties. Such as the weather conditions, the properties of the materials used and the standard of workmanship, and the behavior of occupants of the building. (Erba et at. 2017) and (Wang et al. 2005) state, that there is a significant performance difference depending on the uncertainties in weather files. The long-life of the building makes it probable to work with weather that might change because of global warming. De Wilde and Coley (2012) demonstrate how substantial is to design buildings that account for climate change and that can operate well in future climates. The climate change, the use of synthetic weather files, and the measurement from weather station sited at a distance from the location are presenting sources of uncertainties in weather data.

Therefore, the selection of suitable weather data files can have a significant effect on the prediction of heating demand. (Eames et al. 2011) state, that the appropriate improvement of the data resources and the use of the site-specific weather information for each building could solve these uncertainties.

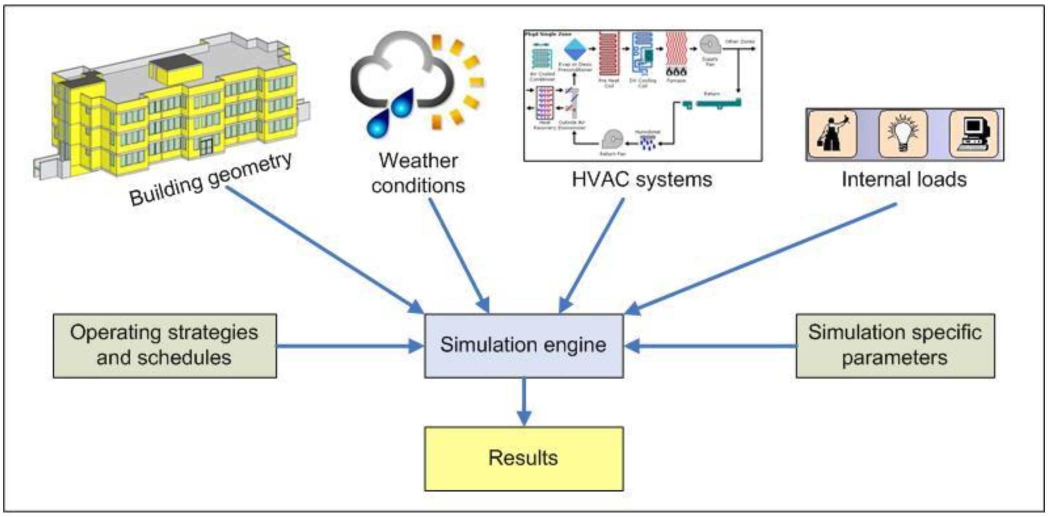

Figure 1-2 General data flow of simulation engines (Source: Maile et al. 2007)

1.3.3 Weather file for building performance simulation

Weather data general requirements:

The weather data requirement comprises averaged or integrated hourly values of air temperature, humidity, solar radiation, wind speed, and wind direction; reliant on the simulation purposes and on the problem required to be solved (Hensen 1999). The data should include a representative winter and summer periods for heating and cooling energy prediction. The extreme conditions are needed for the sizing of the systems. For instance, studying natural ventilation need wind data and studying daylighting need illuminance data (Ward 1996). Hence, it is essential to know the sources of the data, its reliability, and its purposes (Harriman et al. 1999, Crawley 1998). Traditional weather data for simulation is a one-hour time step, and that is not short enough. (Janak and MacDonald 1999) state, that the hourly record of data omitting much information and could result in significant variation (as large as 40 %) in illumination calculations. Another fundamental issue about the weather data is to have clean data, which means there are no missing or negative values and the data should be suitable for the software; bad data breaks software.

The following points propose the features necessary for ideal weather file:

- comprise examples of characteristic conditions,
- include examples of extreme events,
- use shorter time intervals instead of the typical 1-hour time step,
- not cover areas with variations of local topographies,
- represent the effect of the urban microclimate,
- including the effects of climate change and considering future weather.

(Herrera et al. 2017) compared the state-of-the-art to these general requirements and founded that there are several issues with all current and suggested weather construction approaches, but they found the area most requiring attention is the generation of weather files for the urban zones.

The weather data information and availability

(Herrera et al 2017) and Hensen (1999) reviewed the available weather data for building simulation. The widespread form of the weather data is a file contains 8760 hourly records or 8784 hours for a leap year. The one hour is a typical time step and a regular observation interval for the human observer. Until the 1990s most weather observations were made manually. Now with automated systems, the observation can be done every view minute. The building performance simulation field relays on data that generally observed for purposes other than building energy modelings such as aviation, forecasting, and agriculture. The building energy modeling field must make their data for many reasons. The requirements of the engineering field have received less consideration. Values that are not crucial for aviation are not observed. Aviation neglected the incident solar radiation data and it is typically not observed. The low wind velocity observation is typically unreliable and is not essential for aviation, but it is crucial for building natural ventilation.

The weather data items that are typically used in the simulation are listed in Table 1-1 which presents the weather items uses and sources. Air Temperature is needed for exterior surface convection modeling, infiltration and ventilation heat gains. They are universally observed, but not considering the local effect; weather observed at airports would not match necessarily urban site. Humidity is needed for latent heat transfer and equipment's performance, and it is commonly observed. Irradiance needed for fenestration calculation, exterior surface heat balance and solar thermal modeling; It is sparsely measured and generally modeled. Wind velocity and direction used for exterior surface convection, infiltration and natural ventilation; they are generally observed; both wind velocity and direction in the urban setting will be very modified compared to the rural or airports. Moreover, wind low-velocity observations are typically unreliable.

These days there are a lot of different weather file formats, and they are ordinary spreadsheet friendly and accessible. (Crawley et al. 1999) developed the unique standardized weather data format '. epw' file (Energy plus Weather); for the use of the simulation program EnergyPlus. This format is a simple text-based CSV file with comma-separated data to facilitates data reading and analysis with spread programs.

Table 1-1 The weather data items that are typically used in the simulation (Hensen and Lamberts 2011).

Item	**Model uses**	**Sources**
Dry bulb air temperature	Exterior surface convection infiltration/ventilation(sensible) Equipment performance	Universally observed Local effects
Humidity	Infiltration/ventilation(latent) Equipment performance	Commonly observed
Irradiance	Fenestration heat gain Exterior surface heat balance Solar thermal/PV	Sparsely measured Generally modeled Remote sensing opportunities
Wind velocity and direction	Exterior surface convection Infiltration Natural ventilation	Generally observed Significant local effect Low-velocity observation unreliable

Generally, temperature and humidity data are problematic, as it varies between open spaces such as airport location and urban cities including buildings. Also, wind data constituting difficulty, as it remarkably differs because of terrain variations and site obstacles. Furthermore, solar data are rarely available, thus, they are mostly modeled (Hensen and Lamberts 2011). In the past, most of the data available from ground observation stations mainly from airports recorded for aviation purposes. Nowadays, some sources integrate remote sensing (satellite) data which has been tested against ground data. The accuracy of satellite data is reliable and provides comprehensive global data (Voogt and Oke 2003).

Typical Metrological Year TMY

A fundamental aspect of weather data for building simulation is the so-called typical weather year. The idea is to estimate the performance with a simulation with a single year. Wilcox and Marion (2008, pg. 1) described this reference year as *„A typical meteorological year (TMY) data set provides designers and other users with a reasonably sized annual dataset that holds hourly meteorological values that typify conditions at a specific location over a longer period of time, such as 30 years"*. The period is subject to data available at the site. The empirical approach (Sandia Method) is used to select the most representative months from these years of records and combine them in a single full year. In order to evaluate the representativeness of the months, the cumulative distribution functions are used (Figure1-3). The month which matches well the long-term cumulative distribution will be selected. For instance, all 30 Januarys from the 30 years of data were tested, and the most typical one was selected and included in the typical metrological year. Five weather variables were treated in the same manner: dry bulb temperature, dew point temperature, direct normal radiation, global horizontal radiation and wind speed, which are the essential parameters for the building performance simulation (Eames 2015). TMYs were updated to TMY2 with additional advanced solar models and providing additional value to dry bulb and dew point temperatures and giving less attention to wind speed (Marion 1995). TMY2's record period is 1961–1990, while the updated version TMY3 apply a similar procedure and developed with the base time-spans 1976–2005. The TMYs are used for the comparison of alternatives during design and to assess the compliances with building standards, codes and green building rating systems points (Fernández et al. 2015). However, TMYs are not designed to provide meteorological extreme, and there is no apparent effort to represent design conditions. Thus, TMYs used with caution for uncertainty equipment sizing and net-zero analysis. Therefore, there is an explicit effort over the years to generate extreme weather data (Levermore 2006).

Table 1-2 illustrates examples of typical weather files used worldwide. Although weather files were established by different sources and/or methodologies creating distinct file types, some of them share common file formats such as the EPW format.

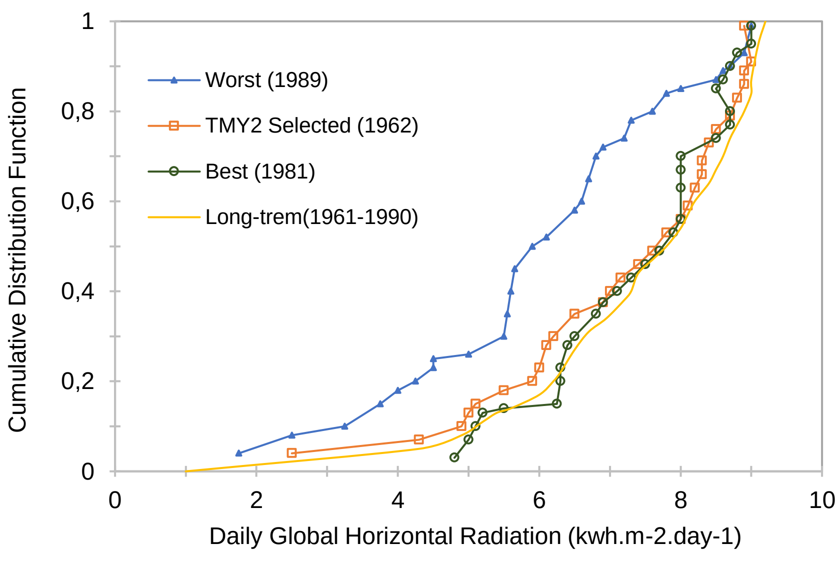

Figure 1-3 Cumulative distribution functions for June global horizontal solar radiation for Boulder, Colorado (example from TMY2 processing) (source: Wilcox and Marion 2008)

Table 1-2 Recent typical metrological year weather data sets

Weather data sets		Geographic coverage	Period
Acronym	Name		
RMY	REPRESENTATIVE METEOROLOGICAL YEAR	AUSTRALIA 80 LOCATIONS	1967–04
ISHRAE	INDIAN TYPICAL YEARS FROM ISHRAE	INDIA 61 LOCATIONS	1991–05
CSWD	CHINESE STANDARD WEATHER DATA	CHINA 270 LOCATIONS	1982–97
UK TRY	TEST REFERENCE YEAR (CIBSE)	The UK 14 locations	1984–13
TMY	TYPICAL METEOROLOGICAL YEAR	USA AND OTHERS 1,020 LOCATIONS	1991–05
WYEC	WEATHER YEAR FOR ENERGY CALCULATIONS	USA/Canada 77 locations	1953–01
IWEC	INTERNATIONAL WEATHER FOR ENERGY CALCULATIONS	Worldwide except for USA and Canada 227 locations	1991–05
IWEC2	INTERNATIONAL WEATHER FOR ENERGY CALCULATIONS2	Worldwide except for USA and Canada 3012 locations	1984-08

International Weather for Energy Calculations (IWEC)

In 2001, The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) developed an International Weather for Energy Calculations (IWEC). Using algorithms to compute solar radiation out of cloud cover and using the interpolation procedures to seal the gaps in the data. The weather data uses were from the National Climatic Data Center (NCDC), the period of record was mostly from 1982 to 1999 and the outcome is unified weather files which were freely available in EnergyPLus format to the use of energy modeling tools for 227 locations worldwide except USA and Canada (Thevenard and Brunger 2002). However, the coverage remains spotty, and there was still frequently request for international weather data; hence the work was revised, improved and the IWEC were updated to IWEC2. The IWEC2 typical years were developed from the historical weather of ISH (The Integrated Surface Hourly) database which was created by the U.S. National Climatic Data Center (NCDC) in 2006 is an archive of weather data recorded by stations in the participating nations. The outcome is a set of IWEC2 weather files for 3012 international locations worldwide except for the United States and Canada (Figure 1-4). The IWEC2 weather file`s period of record varied from 1983-2008 to 1995-2008 and include both observed and derived data elements. The total horizontal and the direct normal solar radiation were derived using several empirical and analytical solar models. Despite the differences between IWEC1 and IWEC2 in periods of record and methods of selecting the typical months, their no different in heating degree days, but very slightly more cooling degree days in moderate climates for the IWEC2 (Huang 2014).

Figure 1-4 ASHRAE International Weather Files for Energy Calculations 2.0 (IWEC2) (source:https://www.ashrae.org/technical-resources/bookstore/ashrae-international-weather-files-for-energy-calculations-2-0-iwec2

Limitation of typical weather year

Generally, data of common weather files are extracted from measured historical weather data, which do not necessarily reflect current weather conditions. Due to the recent change of weather conditions worldwide, the climatic conditions have become drier and warmer, with more solar radiation received by Earth (Yuan et al. 2018). Moreover, the historical data does not represent future climate and it is not able to indicate its effects on weather patterns. Climate change will increase the annual cooling energy demand and will cause a reduction in the annual heating demand due to the rise in average temperature and global solar radiation (Wang et al. 2017). Furthermore, not enough efforts have been undertaken to characterize the extreme conditions, and the files do not represent the design conditions making them not appropriate for uncertainty, resilience, equipment sizing and net-zero analysis (Herrera et al. 2016, Jentsch et al. 2015). Another drawback, representing additional uncertainty in typical weather data, that the chosen site for the collection of weather data measurements are commonly airports neglecting the significant climatic variations from the surrounding urban settlements (Street et al. 2013). The weather files cover large areas and interpolate observations on far distance not considering factors such as distance to the coast, different in elevation and the site-specific condition around the building (Kiesel et al. 2016). All this highlights the limitation of the current representation for the environmental boundary condition in practice for the application of building performance simulation, resulting in unrealistic energy demand simulation.

1.3.4 Urban microclimates

The city climate differs from the surrounding rural areas, caused by the unique nature of urban morphology (Arnfeld 2003). Cities generate atmospheric changes, including a rise in air temperatures compared to the nearby rural areas, a phenomenon documented in different cities around the world (Roth 2007, Oke 1987, Howard 1833). Luke Howard, a premier to identify the impact of local climates on urban areas, proved this phenomenon by comparing his temperature data collection with the recordings of the Royal Society at Somerset House. Howard states that the weather conditions of urban cities represent artificial warmth, as they are significantly impacted by increased population causing a human disturbance. The urban heat island is one of the critical challenges that face the metropolitan areas recently and coupled with two of the most severe issues of the twentieth century: population growth (Landsberg 1981, Oke 1973) and climate change (Alcoforado et al. 2008).

More recently, (Mahdavi et al. 2014) and (Lim et al. 2014) have measured the extent, diversity, and intensity of UHI. (Mahdavi et al. 2014) consider cites like Vienna display strong microclimate variation from one location to another. Figure 1-5 displays the causes of UHI. Building structures acting as canyons reduces the heat transfer from buildings to the atmosphere and blocks winds and reduces convection causing the so-called “urban canyon effect” (Figure 1-6). Moreover, clustered high-rise buildings cause the sunlight to be absorbed and reflected multiple times by its surfaces, increasing the temperature of its intermediate surrounding. The concrete and asphalt used in cites have different thermal properties (increased heat capacity and thermal conductivity) and different surface radiative properties (increased albedo and emissivity).

Materials commonly used in urban cities, such as concrete and asphalt, have different thermal properties (increased heat capacity and thermal conductivity) and different surface radiative properties (increased albedo and emissivity). Cities reveal higher temperatures at night, compared to the day, due to the increased heat absorption during the day causing increased heat emission during the night. The replacement of green areas with urban structures reduces heat loss through evaporation and transpiration (Nuruzzaman 2015). Urban heat islands have negatively impacted on energy usage as well as health conditions. UHI causes a rise in energy demand over the increased use of air conditioning and refrigeration in urban areas producing growing summertime peak energy demand, air conditioning costs, air pollution, and greenhouse gas emissions. Health concerns include heat-related sicknesses and increased mortality rates, as well as reduced water quality (Yow 2007). Those reasons were enough to have intensified worldwide interest in investigating urban heat islands.

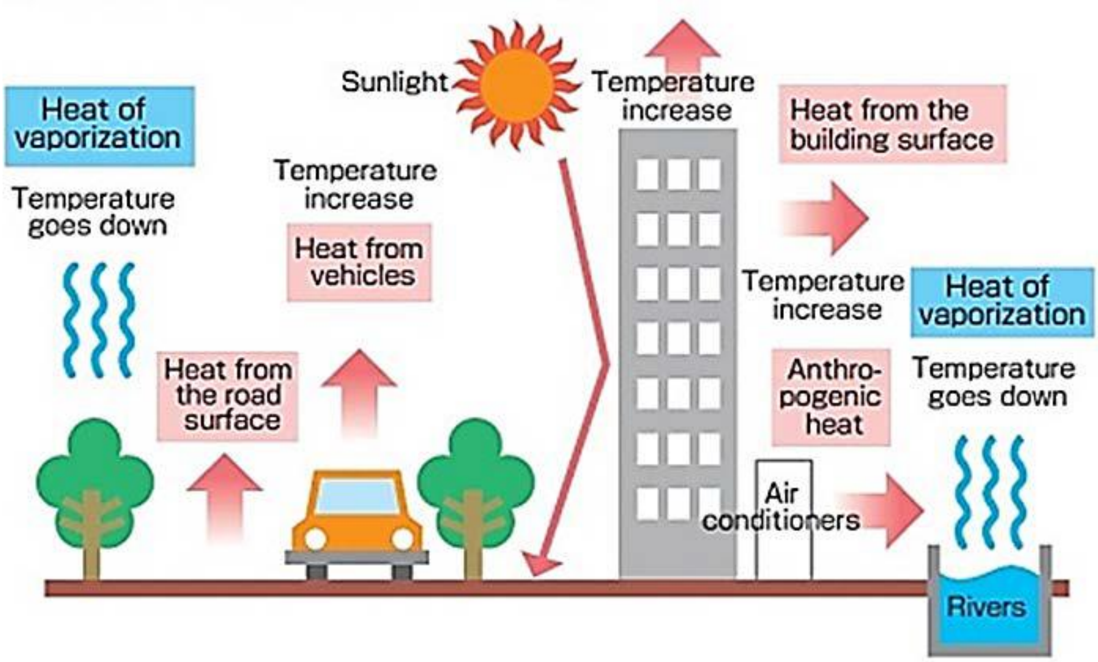

Figure 1-5 Urban heat island causes (Source: http://www.gardinergreenribbon.com/)

Cites moreover alter turbulences (Roth 2000), enhance storms (Bornstein and Lin 2000), change urban hydrology (Grimmond and Oke 1986), and cause pollutant spreading from roads into the atmospheric boundary layer (Cros et al. 2003). Urban planners and designers currently lack tools and methods to incorporate these urban climate effects into the design of new and existing neighborhoods.

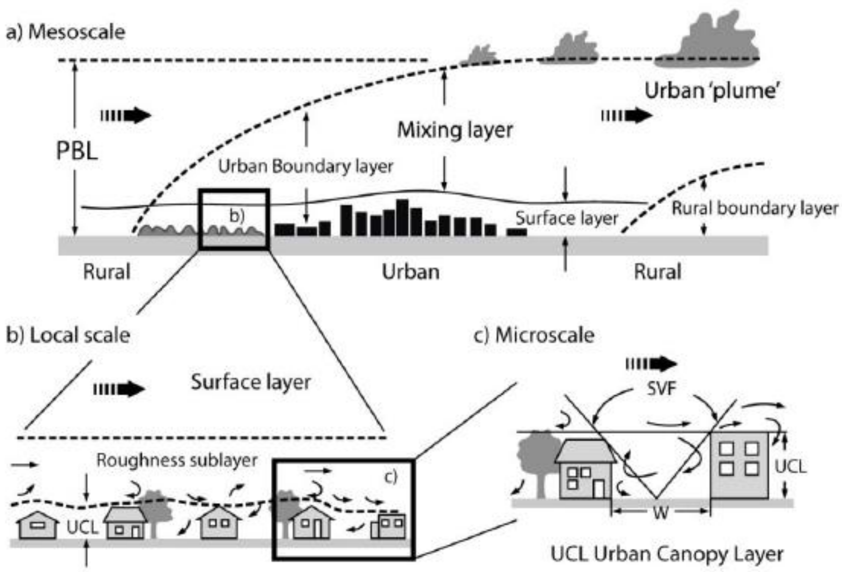

Figure 1-6 Horizontal scales in a city and related vertical atmospheric layers (source: Oke1997)

1.3.5 Urban microclimate representation

Ideally, environmental data should be observed exactly at the project site, subject to all local conditions. Empirically observation suggested that the microclimate can vary significantly across an area consists of even a few streets. (Herrera et al. 2017) intensively assessed the approaches used to generate weather files used in building performance simulation. The analysis covered the essential problems and the limitations of each approach and discussed their agreement with the technical requirements of the ideal weather file for building simulation. Weather data need to express the effect of the urban heat island, climate change, and extreme conditions. This assessment points out that more attention is required to express the site-specific urban microclimate in the weather files.

There are few previous studies on the representation of urban climate. (Erell and Williamson 2006) presented the CAT model as a rural-to-urban weather transformation that uses only meteorological information measured at standard weather stations to simulate the effect of urban geometry on microclimate conditions. The CAT model is developed to calculate air temperature in an urban canyon based on measured weather variables from a reference station located at a neighboring site subjected to the same mesoscale climatic situations. Its primary assumption is that the locations which have similar morphology and surface cover would have matching microclimate circumstances. (Oxizidis et al. 2008) proposed a method for generating urban weather files by coupling EnergyPlus (Crawley et al. 2001) with computational fluid dynamics and mesoscale atmospheric simulations. Another research proposed an urban weather generator (UWG) to estimate urban air temperatures requiring only inputs measured at an operational weather station and accounting for the reciprocal interactions between a building and the urban climate (Bueno et al. 2012). The UWG input parameters identify the urban area and describe its geometry through the main three parameters, average building height, horizontal building density, and vertical to-horizontal urban area ratio. (Vuckovic et al. 2016) established a framework for the representation of the urban environment and established predictive models for the calculation of local differences in the urban climate. However, these new weather data and their influence on energy simulation results have not been thoroughly tested or well documented. In this thesis, UWG one of the approaches used to produce files that aim to represent the urban climate will be tested

2 METHOD

2.1 Overview

In this thesis, the measured and modeled weather data of five consecutive years (2010- 2014) were used as boundary conditions for the simulation of representative two buildings located in multiple locations in Vienna, Austria. For the measured weather information, the data collected at weather stations across the city of Vienna was used. Innere Stadt weather station represents the intensively built-up area in the downtown of Vienna and essentially constituted of offices and residential buildings with an average height of 25 m, and there are little vegetation and no water bodies. The stations in Hohe Warte and Donaufeld were situated in low-density suburban areas and presented the sparsely built-up area and composed of residential buildings and individual houses with an average height of 10m. Seibersdorf considered as the rural reference site outside of the urban area (Lower Austria). Seibersdorf confirmed the definition of rural and not significantly influenced by urbanization and by the existence of large water features or valleys (Oke 2006). The different locations were analyzed to reflect the significant urban climate variances across the city. For the Modeled weather data, the Urban Weather Generator (UWG) was recommended as rural to urban weather transformation which uses metrological information at a rural weather station to estimate the reciprocal interactions between urban geometry and the urban microclimate. The simulated hourly urban air temperatures and relative humidity compared with measurements from the selected weather stations in Vienna. The annual energy demand and heating degree days as performance indicators were then analyzed using the measured and modeled weather as boundary conditions. Furthermore, the results compared to energy demand resulting from simulations based on the standardized weather data usually utilized for Vienna.

2.2 Case study: Vienna

The city of Vienna, the most livable city in the world was used as a case study (Mercer quality of living ranking 2019). The population of Vienna has been growing from 1,564,051 inhabitants in 1991 to 1,867,582 by 2017. By 2029, its population will pass the threshold of 2 million (Figure 2-1). Population growth goes hand in hand with dynamic progress in traffic, the number of cars, the numbers of buildings, and energy consumption (Böhm 1998). All these urban development features influence the urban microclimate and the urban heat island intensity through the absorption of solar energy and its subsequent radiation back to the atmosphere. Urban surfaces modification from natural vegetation to concrete and asphalt change the energy balance and the heat storage capacity of the surfaces. The irregular shape of buildings produces radiation canyons that trap short and longwave radiation. Tall buildings reduce the wind speed which minimizes convention heat loss. The heat which is emitted directly to the urban atmosphere increased because of the increase in energy consumption.

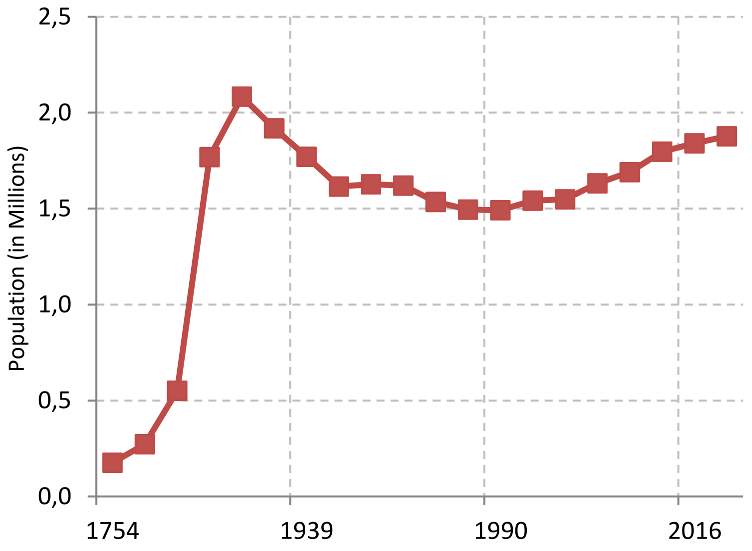

Figure 2-1 Population development of Vienna.

Figures 2-2 and 2-3 provide an overview of the development of the mean annual measured temperature from 1990 to 2012 across different urban typologies in Vienna. Vienna was chosen due to the accessibility to data from the metrological weather station and the information related to the urban characteristic such as average building height, site coverage ratio, vegetation, etc. Vienna regularly hosts urban planning conferences and presented as the best practices applied in the area of urban and environmental technologies, and is often used as a case study by urban planners. The population growth – together with the dense network of weather stations –makes Vienna an ideal city to test the urban microclimate.

Figure 2-4 presents the different urban fabric types in Vienna (Stiles et al. 2014). The nine urban space types characterized by the building typology, topography, local climate, vegetation-specific features, and proportion of the sealed area. (Stiles et al. 2014) addressed that microclimate conditions are highly varying from one urban fabric to another.

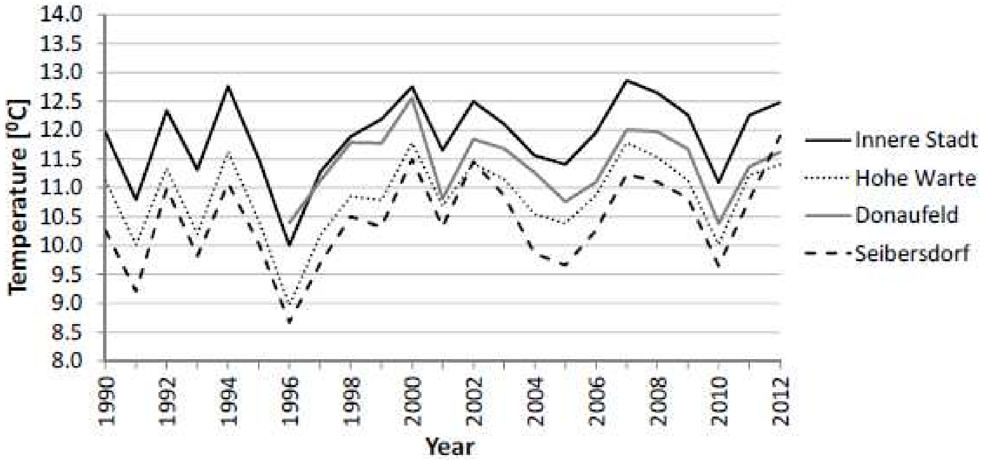

Figure 2-2 Development of mean annual air temperatures throughout 22 years (source: Vuckovic et al. 2014)

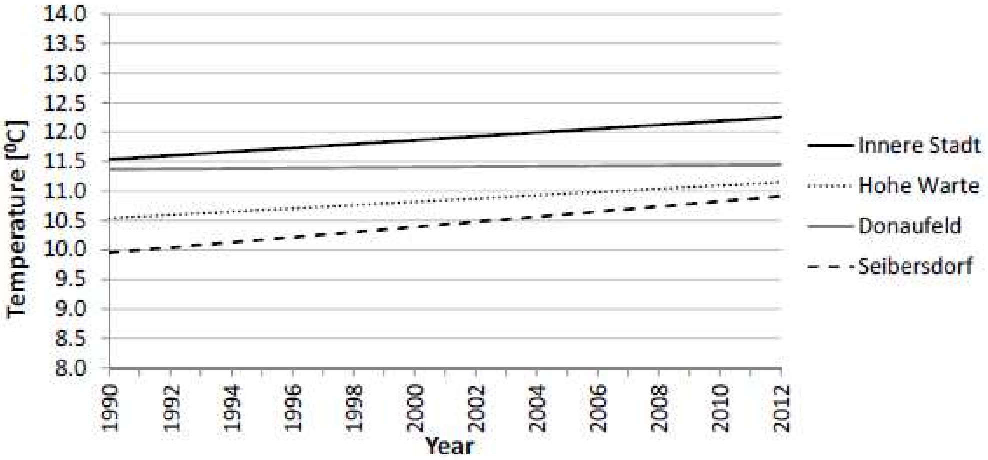

Figure 2-3 Trend lines for the long-term development of mean annual air temperatures across the four locations (source: Vuckovic et al. 2014)

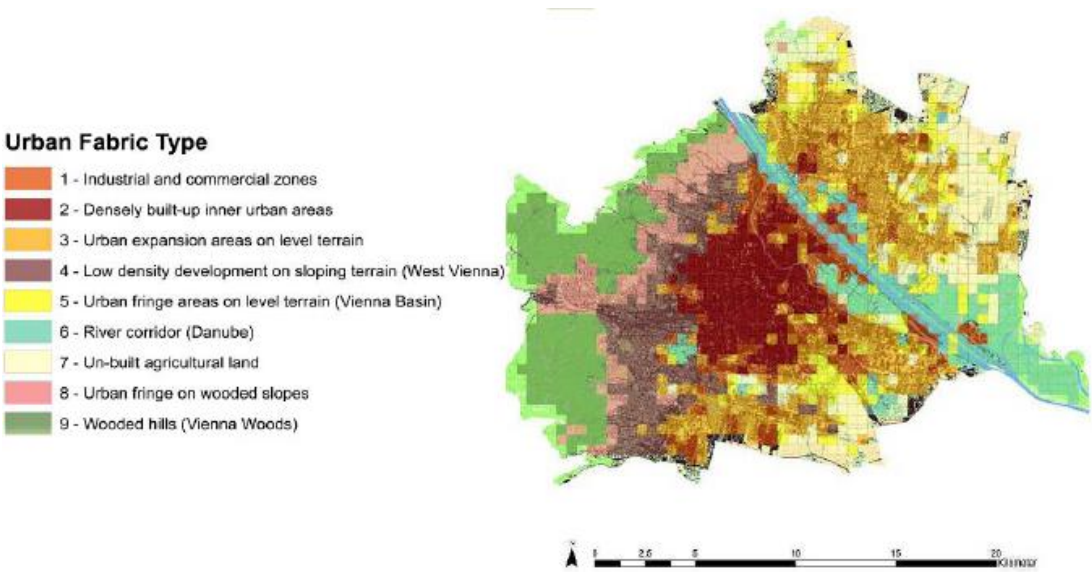

Figure 2-4 Urban fabric types (source: Stiles et al. 2014)

For this thesis, the weather stations representing the U2O "Urban unit of observation" were used (Mahdavi et al. 2013, Mahdavi et al. 2014a, Mahdavi et al. 2014b). U2O address the variation of urban heat island effect across the city of Vienna. Different locations in the city of Vienna were chosen for this study; each of these stations is representative of individually different surroundings. Innere Stadt (IS) located at the historic center is representative of the central urban area with a dense mix of compact midrise buildings (3-9 stories) with few or no trees, land cover mostly paved, and concrete and glass construction materials. Donaufeld (DF) and Hohe Warte (HW) are in suburban regions with an open arrangement of compact low-rise buildings (2-3 stories), a considerable quantity of previous land cover in the shape of gardens and trees between the buildings. Mariabrunn (MB) is operating in a scattered distribution of small or medium buildings in a natural setting covered with grass and scattered trees. Seibersdorf (SD) is the rural reference station outside the boundaries of the metropolitan area. It is mostly surrounding by natural grassland and agricultural fields. Figure 2-5 shows the position of the selected U2O within the city of Vienna.

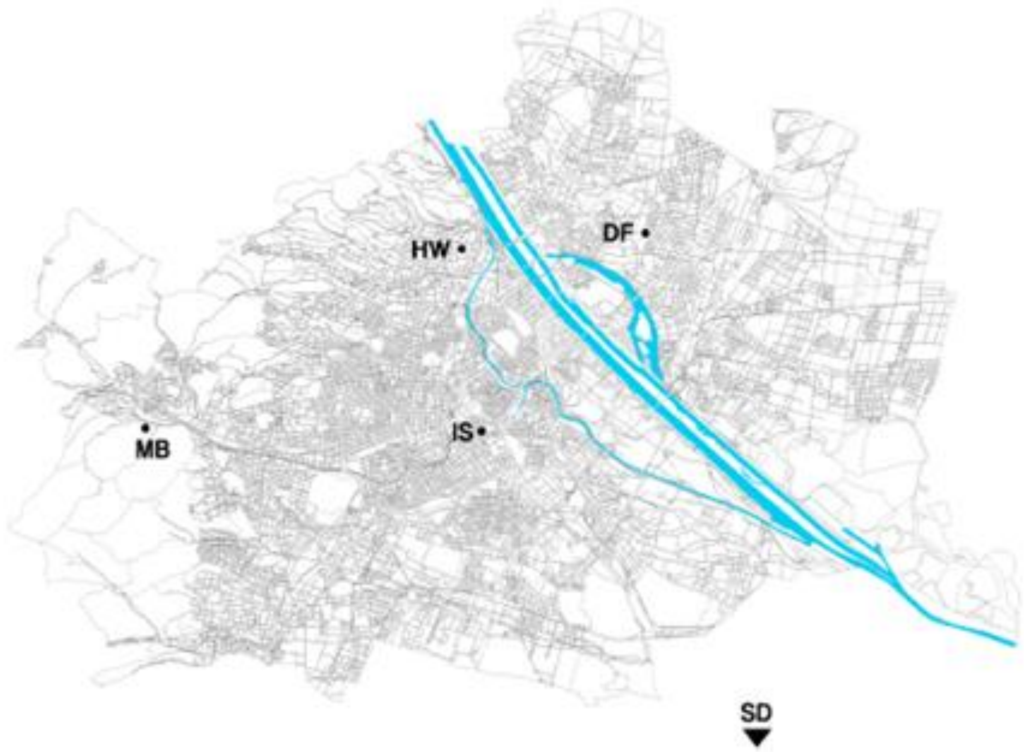

Figure 2-5 General positions of selected locations in and around Vienna.

2.3 Climate Data

The measured weather information employed in this analysis was observed at several stations throughout Vienna. The stations are supervised by Central Institution for Meteorology and Geodynamics (Zentralanstalt für Meteorologie und Geodynamik, ZAMG) which founded in 1851. The quality of the state-of-the-art products and services offered is achieved through insights from research and development programs in conjunction with the constant development of methods. The ZAMG has been recognized in its specialist areas as Austria's representative in the relevant international organizations for many years and considered being a reliable source of temperature data (Böhm 1998). Illustrated in Figure 2-6, ZAMG offers meteorological information from more than 250 meteorological stations distributed in all climate regions and altitudes Austria-wide. ZAMG meteorological system incorporates a wide range of sorts of observation stations, for example, semi _automatic weather station, and stations which are extra directed (two times per day at 6 am and 6 pm) and the previous model situated in orographically complex terrain for extra data concerning precipitation occasions.

The data sets provided weather information about air temperature, relative humidity global solar radiation, precipitation and wind speed for the chosen investigation period from 2010 until 2014. The conversion from metrological weather file to energy plus weather file was required. Elements a tool developed by Big Ladder Software is a comprehensive, integrated tool appropriate for dealing with all current assignments related to weather files. Elements were used to read, create, adjust and manipulate the weather files. Table 2-1 presents a summary of the used weather stations and Table 2-2 shows information about the measurement height at the used weather station.

Figure 2-6 Meteorological observation points in Austria (image provided by ZAMG)

Table 2-1 The weather stations representing the nominated U2Os

	Name	Classification	Coordination	Station Elevation (above ground) (m)	Site Elevation (m)
IS	Innere Stadt	LCZ 2	Lat 48_11054.000" Long 16_2201.000 0 9.3 177"	9.3	177
HW	Hohe Warte	LCZ 6	Lat 48_14055.000 0" Long 16_21023.000 0 1.9 198"	1.9	198
DF	Donaufeld	LCZ 6	Lat 48_15027.000 0" Long 16_2600.000 0 2 161"	2	161
MB	Mariabrunn	LCZ 9	Lat 48_1200.000 0" Long 16_13059.880 0 2.1 225"	2.1	225
SW	Schwechat	LCZ DE	Lat 48_06039.00 0" Long 16_34015.00 0 2.2 184"	2.2	184
SD	Seibersdorf	LCZ 8D	Lat 47_58035.000 0" Long 16_30018.000 0 2.1 185"	2.1	185

Table 2-2 Height [m] of the measuring instruments (from the ground level) for the selected weather stations. (T) Temperature, (WS) Wind speed,(RH) Relative humidity and (GSR) Global solar radiation

Name	T	WS	RH	GSR
Innere Stadt	9.3	52	9.3	50
Donaufeld	2	13	2	4.5
Hohe Warte	1.9	35	1.9	15
Seibersdorf	2.1	15	2.1	13.5
Mariabrunn	2.1	9.5	2.1	4.5

2.4 Standardized weather file

For this analysis, the standardized weather file (AUT_Vienna.Schwechat.110360_IWEC) utilized in the current thermal simulation practice is used. Where (Schwechat) is a rural area outside of Vienna near the airport and (110360) is the world metrological organization ID assigned to this weather station (WMO2016). The weather information was driven from long-term hourly weather data and supplemented by hourly values of solar radiation estimated from sun path diagram and cloud cover (EnergyPlus 2015). Figure 2-7 presents the header information of the standardized weather file of Vienna; the beginning of the header illustrates the location and the format of the weather file; for this situation IWEC (International Weather for Energy Calculations). The header also comprises information like longitude, latitude, time zone, elevation. It also shows the periods of records for the included data, annual design conditions, extreme periods and holiday periods.

```
LOCATION,VIENNA_ SCHWECHAT,-,AUT,IWEC Data,110360,48.12,16.57,1.0,190.0
DESIGN CONDITIONS,1,Climate Design Data 2009 ASHRAE Handbook,,Heating,1,-
TYPICAL/EXTREME PERIODS,6,Summer - Week Nearest Max Temperature For Peric
GROUND TEMPERATURES,3,.5,,,,4.59,1.39,0.52,1.27,5.60,10.44,15.00,18.30,1S
HOLIDAYS/DAYLIGHT SAVINGS,No,0,0,0
COMMENTS 1,"IWEC- WMO#110360 - Europe -- Original Source Data (c) 2001 An
COMMENTS 2, -- Ground temps produced with a standard soil diffusivity of
DATA PERIODS,1,1,Data,Sunday, 1/ 1,12/31
1995,1,1,1,60,C9C9C9C9*0?9?9?9?9?9?9?9A7A7A7A7A7A7*0E8*0*0,-3.4,-5.1,87,S
1995,1,1,2,60,C9C9C9C9*0?9?9?9?9?9?9?9*0B8B8B8B8*0*0E8*0*0,-2.4,-3.6,90,S
1995,1,1,3,60,C9C9C9C9*0?9?9?9?9?9?9?9*0B8B8B8B8*0*0E8*0*0,-1.6,-2.5,92,S
1995,1,1,4,60,C9C9C9C9*0?9?9?9?9?9?9?9A7A7A7A7A7A7*0E8*0*0,-1.2,-2.0,93,S
1995,1,1,5,60,C9C9C9C9*0?9?9?9?9?9?9?9*0B8B8B8B8*0*0E8*0*0,-1.1,-1.9,94,S
1995,1,1,6,60,C9C9C9C9*0?9?9?9?9?9?9?9*0B8B8B8B8*0*0E8*0*0,-1.3,-1.9,95,S
```

Figure 2-7 AUT_Vienna.Schwechat.110360_IWEC, the standardized weather file

2.5 Urban weather generator

For the modeled urban weather data, the Urban Weather Generator (UWG) developed by (Bueno et al. 2012) was used. UWG is a rural to urban weather transformation model which uses metrological information at a rural weather station to estimate the interactions between urban geometry and the urban microclimate and calculate hourly air temperatures and humidity inside urban canyons. The model requires as input a rural Energy plus weather file and the *.xml input file, which describes the morphological and geometric characteristics of the city and the reference site. This tool has been satisfactorily tested and validated against field measurements at two cities: Basel, Switzerland and Toulouse, France and several neighborhoods in Singapore (Bueno et al. 2012). The error of the resulting simulated hourly values remains inside the range of air temperature variation measured in various points inside the specific urban part of the tested cities. UWG is appropriate and reliable and presented an alternative to computationally expensive simulations. This tool performs well for different climate types (rainy, dry/cloudy, and dry/clear) and for various reference sites which validates UWG's robustness and suitability as an urban simulation engine. The produced transformed weather file (epw) is suitable for several buildings performance simulation software which validates its versatility. The UWG has worked properly in cities in Europe where the morphology is homogeneous with no or few trees. The UWG shows reliable results when tested against field data from the city of Vienna in dense urban locations in the framework of the EMULATE project 2017. Energy conservation concepts are the base for this model mechanism. UWG comprises four connected modules illustrated in (Figure 2-8 and 2-9):

(1) the rural station mode (RSM) calculates sensible heat fluxes at the weather station,

(2) the vertical diffusion model (VDM) calculates vertical profiles of air temperature above the rural site,

(3) the urban boundary layer model (UBL) calculates air temperatures above the urban canyon,

(4) the urban canopy + building energy model (UC-BEM) calculates based on the energy balance equation, the air temperature and humidity in the urban canyon.

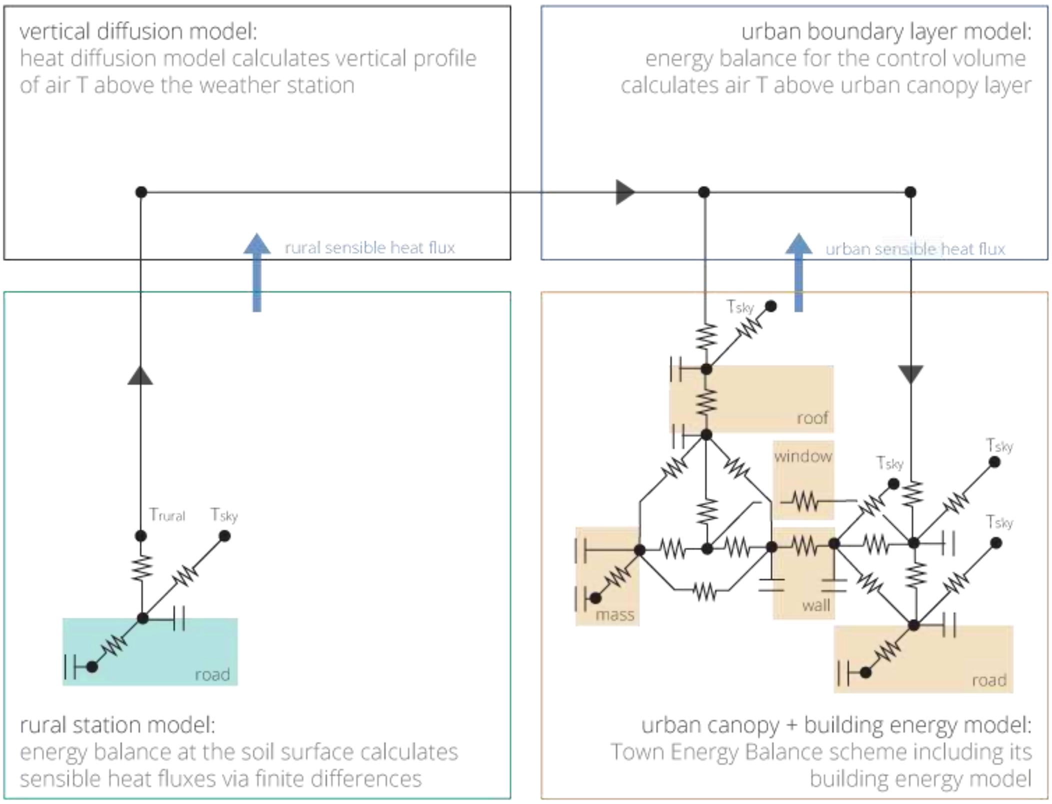

Figure 2-8 UWG Mechanism (Source: Bueno et al. 2012)

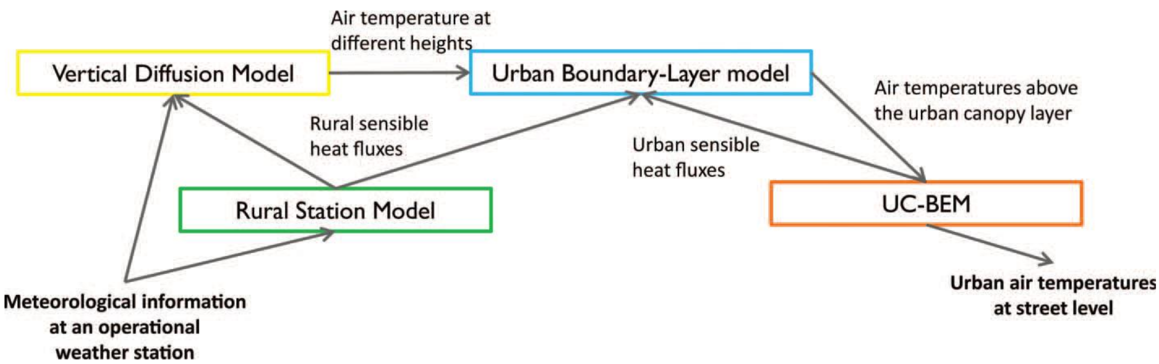

Figure 2-9 Information exchanged among the different models of the UWG (Source: Bueno et al. 2012)

Table 2-3 defines the UWG input parameters that characterized the urban morphology, geometry, and surface materials. Sensitivity analyses were carried out to distinguish the most sensitive parameters and then minimize the user inputs (Nakano et al. 2015). Vertical to the horizontal built ratio (total facade area/site area), horizontal building density (total building footprint/site area), and vegetation were found to be the most essential.

Table 2-3 UWG Input Parameters, unit and range (source: http://urbanmicroclimate.scripts.mit.edu/uwg_parameters.php)

	Parameter	**Unit**	**Range**		**Parameter**	**Unit**	**Range**
Construction				27	Nighttime heating set point	hours	1 - 24
1	Albedo	-	0 - 1	28	Daytime set point end [advanced setting]	°C	
2	Emissivity	-	0 - 1	29	Amount of heat released to canyon	-	0 - 1
3	Names	-		30	Initial temperature [advanced setting]	°C	
4	Thickness	-	0 - 1	**Urban area**			
5	Thermal conductivity	$W.m^{-1}K^{-1}$		31	Average building height	m	
6	Volumetric heat capacity	$J.m^{-3}K^{-1}$		32	Site coverage ratio	-	0 - 1
7	Vegetation coverage	-	0 - 1	33	Facade-to-site ratio	-	0 - 1
8	Inclination	-	0 - 1	34	Sensible anthropogenic heat	$W.m^{-2}$	
9	Initial temperature	°C		35	Tree coverage	-	0 - 1
Glazing				36	Non-building latent heat	$W.m^{-2}$	
10	Window to wall ratio		.2 -.4	37	Neighborhood characteristic length	m	
11	Total window U-value	$W.m^{-2}K^{-1}$		38	Vegetation Properties	-	
12	Total solar heat gain coefficient	-	0 - 1	39	Latent fraction of trees	-	0 - 1
Building				40	Latent fraction of grass	-	0 - 1
13	Daytime internal gain	$W.m^{-2}$		41	Albedo of vegetation		0 - 1
14	Nighttime internal gain	$W.m^{-2}$		42	Vegetation participation begin month	month	
15	Infiltration	ACH		43	Vegetation participation end	month	
16	Ventilation	ACH		**Boundary Layer Parameters**			
17	Floor height [advanced setting]	m		44	Daytime boundary layer height	m	
18	Radiant fraction of internal heat gains	-	0 - 1	45	Nighttime boundary layer height	m	
19	Latent fraction of internal heat gains	-	0 - 1	46	Reference height	m	
20	Cooling system type	n/a		Reference site			
21	Cooling system COP			47	Latitude	o	
22	Cooling capacity of cooling system	$W.m^{-2}$		48	Longitude	o	
23	Efficiency of heating system	-	0 - 1	49	Reference site obstacle height	m	
24	Daytime cooling set point	°C		50	Temperature measurement height	m	
25	Nighttime cooling set point	°C		51	Wind measurement height	m	
26	Daytime heating set point	°C					

In this study, the characteristics of the urban area which were hypothesized to affect the microclimate variation in the investigation area were identified. The geometric urban parameters such as average buildings´ height, built area fraction, and the built surface fraction is identified in Table 2-4. The physical properties such as albedo, emissivity, and the specific heat capacity are described as the thermal properties of urban surfaces and presented in Table 2-5. The anthropogenic heat output in Table 2-6. The detailed characterization of the U2O variables can be found in detail in (Mahdavi et al. 2013, Mahdavi et al. 2014).

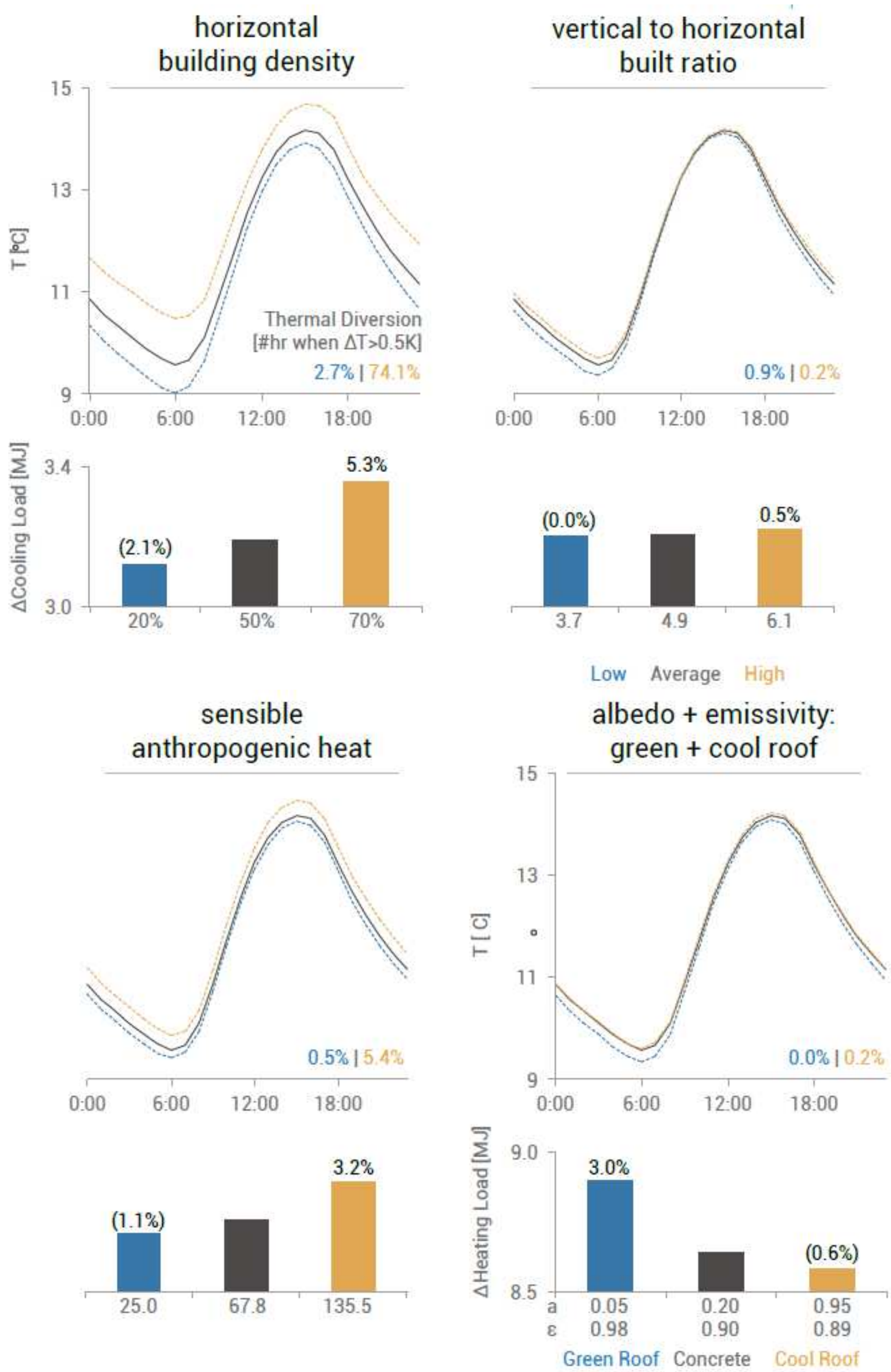

Figure 2-10 Sensitivity analysis for UWG parameters, Boston (source: Nakano et al. 2015

Table 2-4 Used geometric properties

Parameter	**Unit**	**Definition**	**IS**	**DF**	**HW**	**MB**	**SD**
Average building height	m	Average building height in the urban area	22.35	6.15	8	10.1	5.3
Site coverage ratio	-	Describes how close buildings are built in the city Defined by ΣAbldg / Asite	0.41	0.2	0.18	0.04	0.08
Facade-to-site ratio	-	Ratio of the vertical surface area to the urban plan area. Defined by ΣPhwtd / Asite,	1.17	0.34	0.36	0.07	0.09
Tree coverage	-	Amount of tree coverage in the urban area, includes those on the side streets	0.14	0.45	0.48	0.86	0.83
Sensible anthropogenic heat	$W.m^{-2}$	Includes all sensible anthropogenic heat other than from buildings such as traffic, street lighting, and human metabolism	35.04	11.01	17.01	0	0.08

Despite, there were some problems to run *.xml input files required by UWG, some values were used as input parameters and the rest was left to default values. The preparation of the XML file is divided into four different sections: (1) building construction; (2) internal loads from occupants, equipment, and lighting; (3) geometric parameters and anthropogenic heat defining the urban space; (4) and input in concern with the rural reference site. This *.xml input file that defines the morphological and geometric characteristics of the city Vienna of and its reference site Seibersdorf, plus the weather file in the EnergyPlus format (epw) for Seibersdorf the rural reference site was used to run the urban weather generator. The resulting epw file captures the urban heat island effect in the urban location. UWG calculates the urban canyon air temperature and relative humidity which then contrasted with the urban observations from a network of weather stations in Vienna. For this simulation run, most of the parameters set to default values and just set the following parameters: average building height, site coverage ratio, facade-to-site ratio, sensible anthropogenic heat, tree coverage, vegetation participation beginning month, vegetation participation end month, as well as the parameters related to the rural reference site (latitude and longitude).

Table 2-5 Surfaces / Materials properties, Variables for the specification of an urban unit of observation (U2O)

Parameter		Unit	IS	HW	DF	MB	SD
Reflectance/albedo		-	0.15	0.22	0.22	0.35	0.35
Emissivity		-	0.93	0.93	0.93	0.92	0.92
Thermal conductivity							
	Impervious surface	$W \cdot m^{-1} \cdot K^{-1}$	0.80	0.78	0.77	0.77	0.85
	Pervious surface	$W \cdot m^{-1} \cdot K^{-1}$	1.1	1.1	1.1	1.1	1.1
Specific heat capacity							
	Impervious surface	$J \cdot kg^{-1} \cdot K^{-1}$	784.3	822.4	826.4	844.4	766
	Pervious surface	$J \cdot kg^{-1} \cdot K^{-1}$	800	800	800	800	800
Density							
	Impervious surface	$kg \cdot m^{-3}$	2082.1	2064.6	2045.2	20621	2125
	Pervious surface	$kg \cdot m^{-3}$	1000	1000	1000	1000	1000

Table 2-6 Anthropogenic heat output, Variables for the specification of an urban unit of observation (U2O)

Anthropogenic heat output [$kWh \cdot m^{-2} \cdot a^{-1}$]	**IS**	**DF**	**HW**	**MB**	**SD**
Anthropogenic heat output Total	350.04	89.01	177.01	70	67
Vehicles	35	11	17	N/A	7
Buildings	315	78	160	70	60
Human activity	0.04	0.01	0.01	0	0

2.6 Building typologies

2.6.1 Overview

A building typology is composed of different model buildings that represent specific building categories in different age groups. OIB-RL6 defined two building categories based on usage and size, residential and nonresidential buildings. For this thesis, selected two buildings were conducted to simulation, an apartment block (residential), and an office building (nonresidential) (Table 2-7). Each building model is an example of a specific construction period and a specific building type and has certain energetic characteristics.

Table 2-7 Buildings typologies

Building typology	Illustration	Notes
Apartment Block AB		Construction year: 1872 Window Area: 15% U value walls: 1.5 $W.m^{-2}K^{-1}$ U value windows: 2.5 $W.m^{-2}K^{-1}$ Mean floor height: 3.5 m
Office building OB		Construction year: 1945 Retrofitted according to today's standards Window Area: 39% U value wall: 0.35 $W.m^{-2}K^{-1}$ U value window: 1.2 $W.m^{-2}K^{-1}$ Mean floor height: 3.5 m

2.6.2 Building typology 1 (Apartment block)

The apartment blocks are large multifamily and multistory buildings with more than eleven living units, which are mostly located in a larger town. To assess the relevance of these building types, the Austrian statistics (Census 2010 Gebäude und Wohnungszählung) were analyzed (Table 2-8). The basic statistics are giving an account of the frequencies of building types and information about energy-related properties. The table shows that about one-third of all residential buildings in Austria belong to the building category apartment block (AB). As a reference to the apartment block category, a historically five floors residential building has been selected to represent a typical Viennese building constructed in 1872. The heated area is around 9757 m^2. The building description is shown in Tables 2-9, 2-10 and 2-11 below, details about construction materials are resumed in Appendix Table A-1. Table 2-12 presents the default u-values of existing buildings (OIB-RL6 - Leitfaden).

Table 2-8 Number of residential buildings and living spaces (m²) per building typology

	Building Age Class			SFH	RH MFH	AB
	von	Bis				
I		1918	Number of buildings	235.723	36.025	15.228
			Living space (m²)	30.583.052	14.145.992	16.932.198
II	1919	1944	Number of buildings	129.086	18.550	5.025
			Living space (m²)	14.350.764	6.161.368	4.318.376
III	1945	1960	Number of buildings	194.442	19.868	7.727
			Living space (m²)	22.944.091	7.001.308	7.317.536
IV	1961	1980	Number of buildings	489.397	37.104	21.750
			Living space (m²)	65.375.704	14.739.614	28.912.454
V	1981	1990	Number of buildings	246.757	17.592	6.058
			Living space (m²)	33.945.698	7.728.972	8.345.633
VI	1991	2000	Number of buildings	217.150	7.731.781	8.346.942
			Living space (m²)	28.998.468	8.659.864	6.737.756
VII	2001	2010	Number of buildings	174.756	18.557	4.675
			Living space (m²)	26.177.493	8.060.223	5.667.491
		Missing	Number of buildings	58.032	2.809	1.309
			Living space (m²)	6.812.241	1.270.685	1.960.048

Table 2-9 Characteristics of the apartment block model.

Building usage	Residential building
Construction year	1872
Condition	Not retrofitted
Construction type	Heavyweight
Windows	Not shaded
Windows G-Value	0,67
Total Building Area	14501.74 m^2
Unheated building area	4744.43
Heated Building Area	9757.30 m^2
Heated Gross volume	34150 m^3

Table 2-10 Apartment block geometrical and thermal description

BUILDING COMPONENT	AREA m^2	U-VALUE $W.m^{-2}. K^{-1}$
External Wall	5001	1.55
Wall to ground	935.38	1.7
Windows	862.70	2.5
Floor to ground	2062.74	1.25
Roof	2231.81	1.3

Table 2-11 Apartment block envelope description

Gross Wall Area [m^2]	6803.65
Above Ground Wall Area [m^2]	5868.28
Window Opening Area [m^2]	862.70
Gross Window-Wall Ratio [%]	12.68
Above Ground Window-Wall Ratio [%]	14.70
Gross Roof Area [m^2]	2317.50
Skylight Area [m^2]	85.70
Skylight-Roof Ratio [%]	3.70

Table 2-12 Default U-Values of existing buildings (OIB-RL6-Leitfaden). SFH single-family house, MFH multifamily house, FB floor against basement, FL floor between different units, EW external wall, RF roof, win window, g solar energy transmittance, DO door to outside.

Building Component	FB	FL	EW	RF	Win	g	DO
Before 1900 SFH	1.25	0.75	1.55	1.30	2.50	0.67	2.50
Before 1900 MFH	1.25	0.75	1.55	1.30	2.50	0.67	2.50
After 1900 SFH	1.20	1.20	2.00	1.00	2.50	0.67	2.50
After 1900 MFH	1.20	1.20	1.50	1.00	2.50	0.67	2.50
After 1945 SFH	1.95	1.35	1.75	1.30	2.50	0.67	2.50
After 1945 MFH	1.10	1.35	1.30	1.30	2.50	0.67	2.50
After 1960 SFH	1.35	0.65	1.20	0.55	3.00	0.67	2.50
After 1960 MFH	1.35	0.65	1.20	0.55	3.00	0.67	2.50
System construction	1.10	1.05	1.15	0.45	2.50	0.67	2.50
Installation construction	0.85	1.00	0.70	0.45	3.00	0.67	2.50

2.6.3 Building typology 2 (Office building)

The building which has been chosen to represent the non-residential category is an office building. The building is constituted of 7 floors and a basement with a net conditioned area of 3695 m^2, and a floor height of 3,5 m. It was constructed after 1945 and retrofitted according to today's standards. The general characteristics needed for the simulation are listed in the following Tables 2-13, 2-14 and 2-15, details about construction materials are resumed in Appendix Table A-2. The maximum u-value for building component of the thermal envelope are presented in Table 2-16.

Table 2-13 Characteristics of the office building model.

Building usage	Office building
Construction period	After 1945
Condition	Retrofitted according to today's standards
Construction type	Heavyweight
Windows	Not shaded
Windows G-Value	0,67
Total Building Area	4843.84m^2
Unheated building area	1149.1 m^2
Heated Building Area	3694.74m^2
Heated Gross volume	34150 m^3

Table 2-14 Office Building geometrical and thermal description

BUILDING COMPONENT	AREA m^2	U-VALUE W.m^{-2}. K^{-1}
External Wall	5001	0.39
Wall to ground	935.38	0.4
Windows	862.70	1.7
Floor to ground	2062.74	0.39
Roof	2231.81	0.2

Table 2-15 Office building envelope description

	Total	North	East	South	West
Gross Wall Area [m2]	2129.6	495.4	718.9	495.2	420.2
Above Ground Wall Area [m2]	1856.6	440.5	631.6	440.3	344.2
Window Opening Area [m2]	720.2	148.0	281.6	207.9	82.7
Gross Window-Wall Ratio [%]	33.8	29.9	39.2	42.0	19.7
Above Ground Window-Wall Ratio [%]	39	34	45	47	24

Table 2-16 Maximum U values for building components for new and renovated buildings (OIB-RL 6-2019)

Building Component	U-Value Maximum (W.m^{-2}. K $^{-1}$)
External Wall	0.35
Walls to unconditioned roof spaces	0.35
Walls to unconditioned spaces (except roof spaces) and to garages	0.60
Walls adjacent to ground	0.40
Partition Walls between separated units inside of a building	0.90
Walls to neighboring buildings	0.50
Walls (small-scale, less than 2% of overall building's envelope)	0.70
Partition walls inside of units of a building	-
Windows & Glazed Doors (residential buildings)	1.40
Windows & Glazed Doors (non-residential buildings)	1.70
Other vertical transparent building elements	1.70
Other tilted or horizontal transparent building elements	2.00
Vertical transparent elements to unconditioned spaces	2.50
Windows in sloped roofs	1.70
Opaque doors to outside air	1.70
Opaque doors to unheated spaces	2.50
Industrial doors / rolling shutter gates	2.50
Doors between rooms of the same unit	-
Sloped roofs and flat roofs, ceiling slabs to unheated attics	0.20
Floors against unheated spaces	0.40
Floors between different units	0.90
Floors between rooms of the same unit	-
Floors above outside air	0.20
Floors to garages	0.30
Floors to ground	0.40

2.7 Building energy simulation

Over the last years, several buildings performance simulation (BPS) computer programs have been developed. EnergyPlus is the core tool in the field of BPS and is the most used building performance simulator. EnergyPlus is a dynamic, whole-building simulator, which helps architects, engineers, and researchers to calculate buildings´ performance indicators like heating and cooling demand and thermal comfort (Crawley et al. 2001). This software was used for simulation as it can consistently evaluate the thermal behavior of a range of buildings and its mechanical system settings, taking into consideration the general building physics algorithms for heat and mass transfer (Crawley et al. 2008). For the calculation of the energy demand in this study, the input assumptions such as heating and cooling setpoints temperature (thermostat setting), occupancy, internal gains and ventilation rate were used in accordance with the Austrian standard ÖNORM B 8110-5 (2011), “Thermal insulation in building construction, part 5: model of climate and user profiles”. These values were selected according to the usage of the buildings and presented in table 2-17.

Table 2-17 User profile assumptions

Building type	**Commercial**	**Residential**
Ventilation rate [h^{-1}]	1.2	0.4
Internal gains [$w.m^{-2}$]	3.75	3.75
Heating set -point temperature [°C]	20	20
Cooling set -point temperature [°C]	26	27

Each building will be simulated by using the standardized rural whether file, urban modeled and urban measured weather as a boundary condition, to determine the magnitude of microclimate effect on the energy demands of the building. The metric of annual heating and cooling demand will be applied, which is the annual sum of the energy demand for either heating or cooling normalized by the building’s conditioned area.

The second indicator to estimate the building`s heating loads is the heating degree days (HDD 20/12). The heating energy needed for a building at a particular area is straightforwardly corresponding to the quantity of HDD in that area which describes the particular weather in a specific area. It is the number of degrees that a day's average temperature is below 12^{o} Celsius, which is the temperature below it the buildings need to be heated. The HDDs are derived from the calculation of outdoor air temperature and room temperature calculated as per formula (1) following the Austrian standard ÖNORM B 8110-5 (2011).

$$HDD_{20/12} = \sum_i \left(\theta_{i,h} - \theta_{e,i}\right) \cdot d_i \qquad (1)$$

where:

$HDD_{20/12}$ Heating degree days, in Kd/a

$\theta_{i,h}$ Mean indoor temperature according to Table 2 (Standard and Guidelines), in °C

$\theta_{e,i}$ Average outdoor temperature in each month, in °C

d_i Month days, if $\theta_{e,i} < 12$ °C, in d

Cooling degree hours (CDH) are used to indicate the effect of outside air temperature on building cooling demand during a specified period. They represent the sum of the hours when the outdoor air temperature at a specific location is higher than a specified base temperature (26°C in this case). This indicates how much cooling will be required in the building and calculated as per formula (2).

$$CDH_{26} = \sum \left(\theta_{i,h} - \theta_{e,i}\right) \cdot h_i \qquad (2)$$

where:

CDH_{26} Cooling degree hours, in Kd/a

$\theta_{i,h}$ Mean indoor temperature according to Table 2 (Standard and Guidelines), in °C

$\theta_{e,i}$ Outdoor temperature, in °C

h_i Hours, if $\theta_{e,i} > 26$ °C, in h

2.8 Research question

Since the presently available climate dataset utilized as a part of building simulation programming fundamentally originates from weather stations situated in rural domains, the effect of the urban heat island and microclimate on energy demands of buildings may not be successfully represented. Recently few researchers deal with the development of methodologies for the construction of urban weather files, originating from rural stations. These methods account for microclimate impact on temperature and relative humidity. This research paper intends to compare the effects of morphed rural weather files corresponding to urban climate on buildings' energy performance simulation. The research questions include: What is the difference in energy demand of buildings simulated by standardized and site-specific weather files? How much can discrepancies between rural and urban microclimate affect the energy demand of buildings? Can the urban weather generator reduce these differences?

3 RESULTS AND DISCUSSION

3.1 Overview

To explain the results of the present thesis the microclimate data obtained from the observations at the metrological stations will be analyzed. Afterward, the microclimate indicator the seasonal average of the main four weather elements will be compared to their corresponding values in the standardized weather file commonly utilized in simulations for the city of Vienna. Then, the modeled hourly urban weather files by the urban weather generator will be validated and tested by comparing it against field measurements. Finally, the results of buildings thermal performance for two examples of buildings will be analyzed using standardized, measured and modeled weather files.

3.2 Weather analysis

Vienna is known for its placid continental climate, one with unstable patterns and sizable seasonal temperature variance. The studied period covered five consecutive years (2010 - 2014). In this period, the summer in 2012 was the hottest and the winter in 2010 was the coldest. The winter in 2014 was a mild one; 1.8 ° C above the long-term average making it the eighth warmest winter in the 248-year of history. In this thesis, the observed weather data for the studied period across five locations were structured and analyzed. The Figures 3-1 to 3-4 illustrate the seasonal mean of the four main microclimate elements; temperature, absolute humidity, global solar radiation and wind speeds in the heating and cooling seasons. These weather elements are changing as climate change continues which directly affects the energy demand of buildings.

Generally, there are significant microclimatic variations in all four weather parameters across the observed urban locations because of the different morphologies and materials of the urban landscape. Additionally, there are substantial discrepancies between the weather files from metrological stations and the standardized file. The standardized data underestimates the temperature and global solar radiation, which might have significant implications on the thermal performance of the buildings.

The mean seasonal air temperature is constantly higher particularly at densely built central urban area (IS), both in summer and winter periods influenced by the urban heat island effect (Figure 3-1).

The surfaces of the tall buildings reflect and absorb the sun radiation multiple times, the modification of land surfaces and the heat waste generated by energy usage tend to modify in the energy balance of the built environment and increase the average temperature. Innere Stadt shows the maximum absolute difference in temperature between the urban locations and the standardized file, 3.2 K higher in 2012 and 4.7 K higher in 2014 in summer and winter respectively. The maximum difference between the urban areas was about 2.3 k (IS/MB 2014) in the summer.

Figure 3-2 shows that the average absolute humidity in urban locations is constantly lower than that of surrounded rural areas, due to the rapid runoff precipitation and the absence of evaporation and transpiration from green areas in urban domains. Innere Stadt shows the maximum difference in absolute humidity between urban locations and standardized weather, about 2.8 g.m^{-3} in 2012 in summer. Due to the higher fraction of vegetative cover, the mean seasonal absolute humidity was found to be higher at Seibersdorf. The maximum difference in absolute humidity between the urban locations is 1.2 g.m^{-3} (IS/SD 2014, Summer).

The variation of global solar radiation shown in Figure 3-3, which is rather small across the observed areas however its change from one year to another is considerable. The location Donaufeld displays the maximum difference of the global solar radiation, about 10 W.m^{-2} more in 2013 and 3.5 W.m^{-2} more in 2012 in summer and winter respectively, compared to the earlier period. Therefore, it may be speculated that this difference might cause discrepancies in both cooling and heating demand.

Usually, the wind sheltering effect decreases the wind speed intensively in urban locations compared to an open area. The changes referred to the higher surface's roughness in the urban locations, as compared to adjacent rural areas (Roth 2000). According to the stations' measurements, the wind speed is constantly and considerably higher at Hohe Warte and Innere Stadt (Figure 3-4). The explanation is the difference in the measurement height and the position of the anemometers at the studied locations. According to the Table 2-2, the anemometers at Hohe Warte and Innere Stadt are positioned at heights 35m and 52m from ground level, while at Donaufeld and Mariabrunn placed at heights 13m and 9.5 m. This higher anemometer location could be the reason for recorded higher speeds at Hohe Warte and Innerestadt.

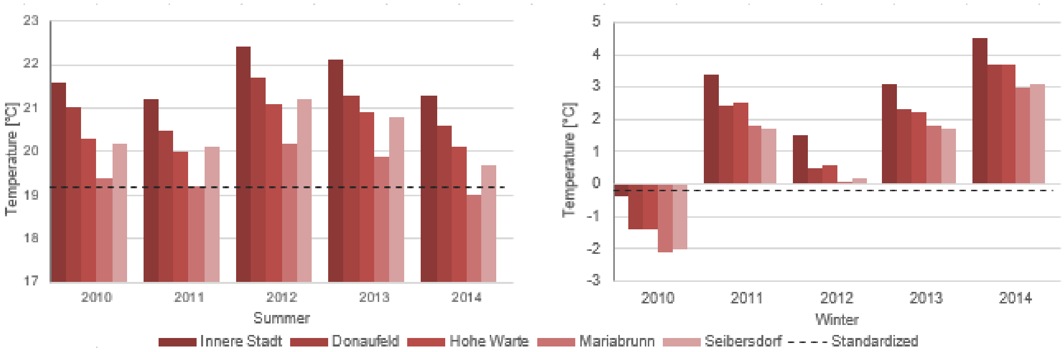

Figure 3-1 Mean seasonal temperature, summer and winter period

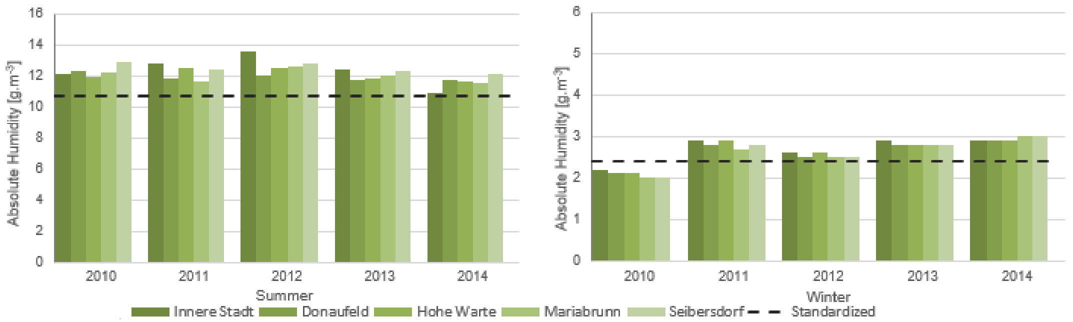

Figure 3-2 Mean seasonal absolute humidity, summer and winter period

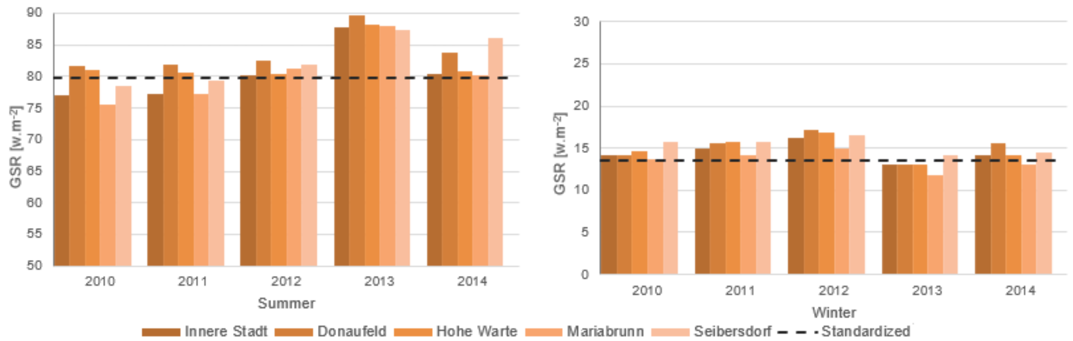

Figure 3-3 Mean seasonal global solar radiation, summer and winter period

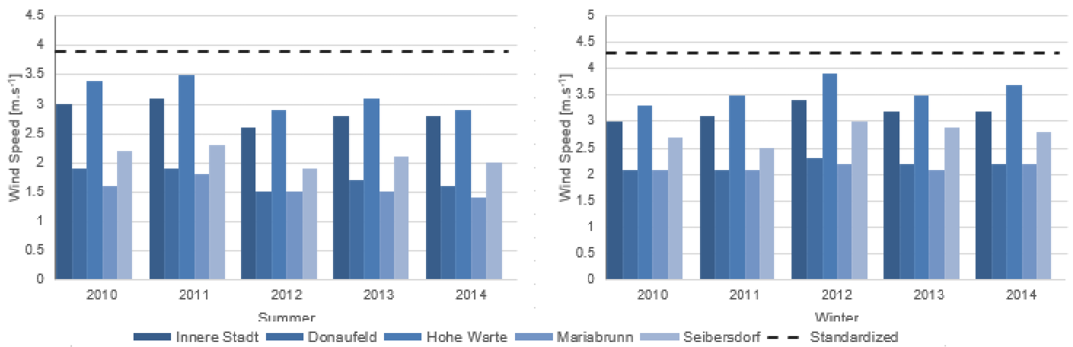

Figure 3-4 Mean seasonal wind speed, summer and winter period

The significant discrepancies between the weather files from the meteorological stations at the urban location mean that the weather cannot be representative for all sites in the city, particularly not for Innere Stadt location where the higher temperature values were recorded. The comparison of the weather of the earlier period (standardized weather) with data from the new period (the five years from 2010 to 2014) shows that there is a significant difference between the old and new periods regarding all four weather parameters. Due to ongoing climate change, the temperature and global solar radiation were drastically underestimated in the standard file, and this could lead to the misestimation of the energy demands. Overall, the results show that the change in weather elements trends to warmer and drier weather with more solar radiation.

3.3 Urban weather generator results

The evaluation of the UWG consists of introducing rural data as inputs in the model and then comparing the calculated urban weather file to the simultaneously measured data at the urban location. Figures 3-5 and 3-6 represent one diurnal cycle; these are the hourly values for a day averaged over the whole month. For this thesis, the results for January, April, July, and October are representing one month for each season (winter, spring, summer, and autumn). Urban heat island exhibits significant diurnal behavior, and the Tu-r maximum difference is generally most apparent at night. As can be seen, the UWG can capture the UHI effect, and satisfactory fit the observations. The statistical results of this study are illustrated in Table 3-1. To understand the deviation of the data obtained by the simulation runs from the measured data set, the root means square error (RSME), the mean bias error (MBE), and the maximum urban heat island effect (UHIMax) were calculated. An RMSE of zero means that the urban temperature was predicted with no error and the file created from this data would equal the observation. The root mean square error (RMSE) between the model and observation is rather small in January which represents winter only 0.4 where the average daily maximum UHI effect is 1.9 K. RMSE in April (spring) is also small only 0.49 where the maximum UHI effect is 2.89 K. In July which represents summer, the RMSE is 1.6 where the maximum UHI effect is 4.2 K, here the model slightly overestimated the temperature at the nighttime. In October RMSE is 0.8 K where the maximum urban to the rural difference is 2.45 K. The most accurate results achieved in winter season which in turn may lead to accurate estimations of the heating demands of buildings when using the modeled weather files for simulations. Except for July, the error stays below 1K the acceptable error in the prediction of urban temperature.

The cumulative error distribution is shown in Figure 3-7. Considering the 1k the expected error associated with UWG predictions which remains inside the range of temperature variation measured in several spots of the same urban zone. 100% of the averaged values in January and 90% in April and October are below 1K.

The results proved the capacity of the urban weather generator to reproduce the UHI effect for different seasons. Accordingly, the UWG can be integrated into existing programs to account for site-specific urban microclimates in building energy simulations. It can also be converted into a fully operative program to predict building energy consumption at the urban scale and the UHI effect, considering the energy interactions between buildings and the urban climate.

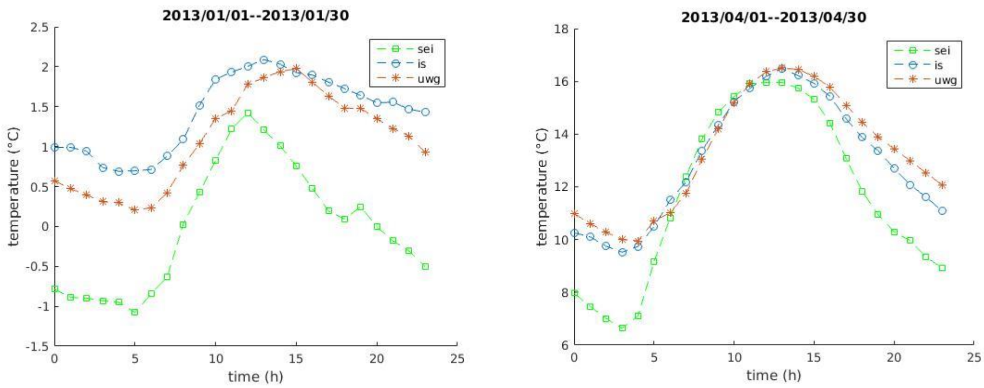

Figure 3-5 Monthly average diurnal cycles for the temperature calculated by the UWG and observed at the location Innere Stadt for January and April.

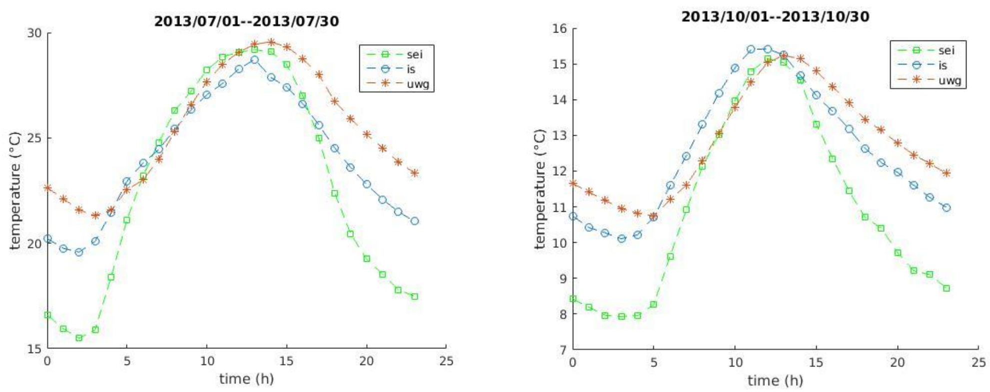

Figure 3-6 Monthly average diurnal cycles for the temperature calculated by the UWG and observed at the location Innere Stadt for July and October

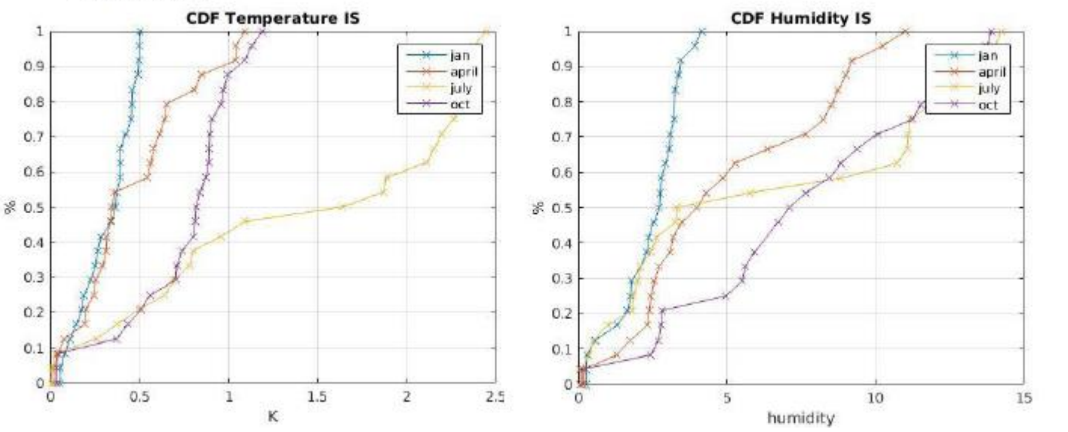

Figure 3-7 Cumulative error distribution for temperature and humidity calculated by the UWG and observed during 2013 at the location Innere Stadt.

Table 3-1 Root mean square error (RMSE), Mean bias error (MBE), maximum difference between UWG and observation, and maximum magnitude of the UHI effect between rural and urban.

Dataset	RMSE [K]	MBE [K]	MaxDif [K]	UHIMax [K]
2013-01-IS	0.44	-0.41	0.62	1.93
2013-04-IS	0.49	0.14	0.89	2.89
2013-07-IS	1.64	1.17	2.45	4.20
2013-10-IS	0.80	0.09	1.38	2.45

3.4 Energy performance simulation results

Each building was simulated with the urban datasets to investigate the impact of microclimate variation on energy demand. Further, the performance indicators heating and cooling demands were analyzed across all urban locations. The variations in the weather data variables were translated into significant variations of building thermal performance. For both buildings typologies, the mean annual heating demand is always less at densely built central urban area (IS) where the higher temperature translated into lower heating demand for both buildings. The AB displays the highest heating demand absolute variation across urban locations, reaching 12.13 kWhm^{-2}a^{-1} (IS/MB 2010) shown in Figure 3-8. The OF reaches maximum cooling demand absolute variation between urban locations about 8.08 kWhm^{-2}a^{-1} (IS/MB 2011) shown in Figure 3-12.

The results were further compared to the same performance indicators derived from simulations based on the standardized weather data commonly used for Vienna. Figures 3-8,3-9,3-11, and 3-12 show the absolute differences in the mean annual heating and cooling load for each building and each location compared to the standardized case. According to the results at all locations the deviations of both buildings from the standardized case from 2010 to 2014 are considerable. The peak deviation from the standardized case is reached at location Innere Stadt, the apartment block in 2014 has 58% (32 kWhm^{-2}a^{-1}) less heating demand, and the office building in 2012 reach 37% (16.26 $kWhm^{-2}a^{-1}$) more cooling demand. The Tables 3-2 to 3-5 quantify the building simulation results and the relative difference in energy demand, for each building between urban sites and standardize case. Looking at the different locations Innere Stadt followed by Donaufeld shows the maximum deviation in heating and cooling demand compared to the standardized case. This might be due to the specific geometric and surface properties of the surrounding urban fabric, affecting thus the heating and cooling systems of this urban domain.

Therefore, the standardize file is not reliable since it does not describe the local climate in each part of the city, and it is based on long ago measurements. Weather data provided by a climate database based on more recent years may be more reliable alternatives when performing energy simulation. However, recent measurements from reference stations located outside the urban area neglected the UHI effects and the microclimatic circumstances in the building site. Which, in turn may lead to significant misestimations of the thermal performance.

To determine the effect of urban to rural differences on energy demand each building was simulated with the simultaneously measured rural dataset observed in Seibersdorf station and then compared to the urban locations. The results suggest that the heating demand differences between urban and rural locations vary considerably and particularly in the dense urban location (IS). The apartment block displays urban (IS) versus rural (SD) deviation in the range of 7.22 to 9.14 $kWhm^{-2}a^{-1}$ and 1.25 to 3.2 $kWhm^{-2}a^{-1}$ for heating and cooling demand respectively. While the office building displays a deviation of 0.85 to 2.41 $kWhm^{-2}a^{-1}$ and 0.5 to 3.14 $kWhm^{-2}a^{-1}$ for heating and cooling respectively. These observations confirm that the UHI effect and the differences between rural and urban microclimates cannot be neglected. To work around this bias and to reduce these discrepancies the urban weather generators can be used to transform the rural weather data (Seibersdorf) into urban.

Moreover, the heating degree days and cooling degree hours were analyzed and presented in Figures 3-10 and 3-13. A strong correlation between heating energy demand and heating degree days is revealed which means that it could be possible to approximate future energy demand based on HDD. The variations in cooling demand and the cooling degree days during the studied period are not correlated leading to a problematic approximation of future cooling demand based on only CDH. It could be speculated that CDH should be not only a function of the exterior temperature but also of solar radiation and wind speed and direction.

Table 3-2 Heating demand simulation results for the apartment block building (kWhm^{-2}a^{-1}). Percentage difference calculated to compare the standardized case to observation. (ST) standardized weather, (IS) Innerestadt, (DF) Donaufeld, (HW) Hohe Warte, (MB) Mariabrunn and (SD) Seibersdorf.

	ST	IS	DF	HW	MB	SD	IS/ST	DF/ST	HW/ST	MB/ST
2010	86.19	76.99	80.33	83.53	89.12	85.62	12%	7%	3%	-3%
2011		67.73	72.44	73.49	79.43	76.87	27%	19%	17%	9%
2012		67.83	72.26	74.05	77.79	75.05	27%	19%	16%	11%
2013		71.23	75.35	78.34	80.64	79.96	21%	14%	10%	7%
2014		54.61	58.72	61.19	65.5	63.37	58%	47%	41%	32%

Table 3-3 Heating demand simulation results for the Office building (kWhm^{-2}a^{-1}). Percentage difference calculated to compare the standardized case to observation.

	ST	IS	DF	HW	MB	SD	IS/ST	DF/ST	HW/ST	MB/ST
2010	19.34	17.98	18.4	18.84	21.25	18.9	8%	5%	3%	-9%
2011		14.06	15.43	15.53	17.37	16.47	38%	25%	25%	11%
2012		13.91	15.1	15.48	17.08	14.76	39%	28%	25%	13%
2013		14.12	15.41	16.13	17.33	16.35	37%	26%	20%	12%
2014		9.48	10.32	10.99	12.22	11.41	104%	87%	76%	58%

Table 3-4 Cooling demand for the apartment block building (kWhm^{-2}a^{-1}). Percentage difference calculated to compare the standardized case to observation.

	ST	IS	DF	HW	MB	SD	IS/ST	DF/ST	HW/ST	MB/ST
2010	4.15	9.2	9.39	6.85	9.89	7.63	-55%	-56%	-39%	-58%
2011		9.02	8.81	5.86	9.23	6.8	-54%	-53%	-29%	-55%
2012		13.25	11.74	8.89	14.67	10.05	-69%	-65%	-53%	-72%
2013		13.65	12.65	10.04	15.13	10.74	-70%	-67%	-59%	-73%
2014		7.97	8.54	5.68	9	6.72	-48%	-51%	-27%	-54%

Table 3-5 Cooling demand for the office building (kWhm^{-2}a^{-1}). Percentage difference calculated to compare to the standardized case to observation.

	ST	IS	DF	HW	MB	SD	IS/ST	DF/ST	HW/ST	MB/ST
2010	28.01	32.8	33	30.24	28.09	31.42	-15%	-15%	-7%	0%
2011		42.4	41.09	39.67	34.32	39.7	-34%	-32%	-29%	-18%
2012		44.27	41.04	39.28	37.9	41.13	-37%	-32%	-29%	-26%
2013		39.44	38.07	35.44	34.41	37.33	-29%	-26%	-21%	-19%
2014		36.26	36.83	33.52	31.33	35.8	-23%	-24%	-16%	-11%

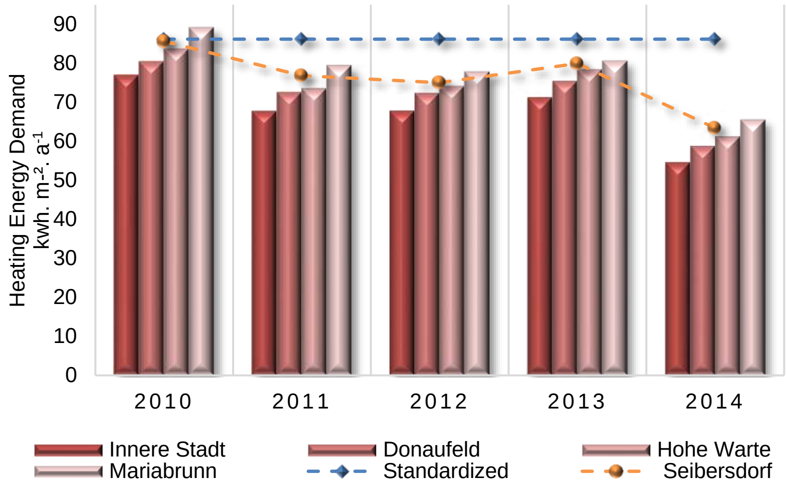

Figure 3-8 Spatial and temporal Variance for mean annual heating energy demand over five years period for AB

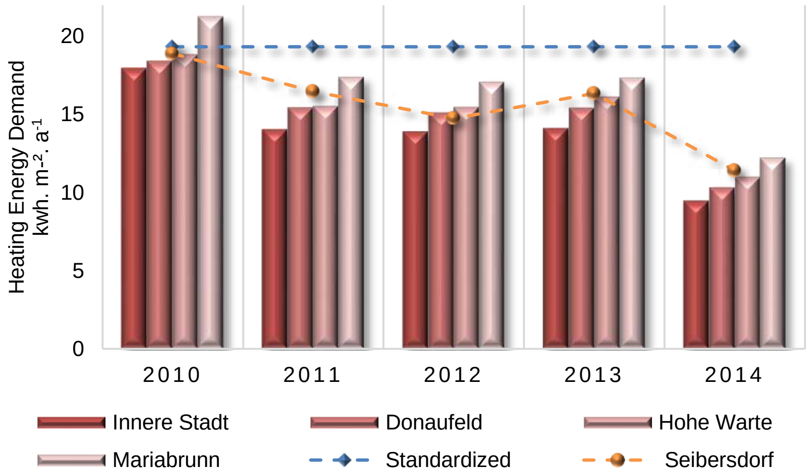

Figure 3-9 Spatial and temporal Variance for mean annual heating energy demand over five years period for OF

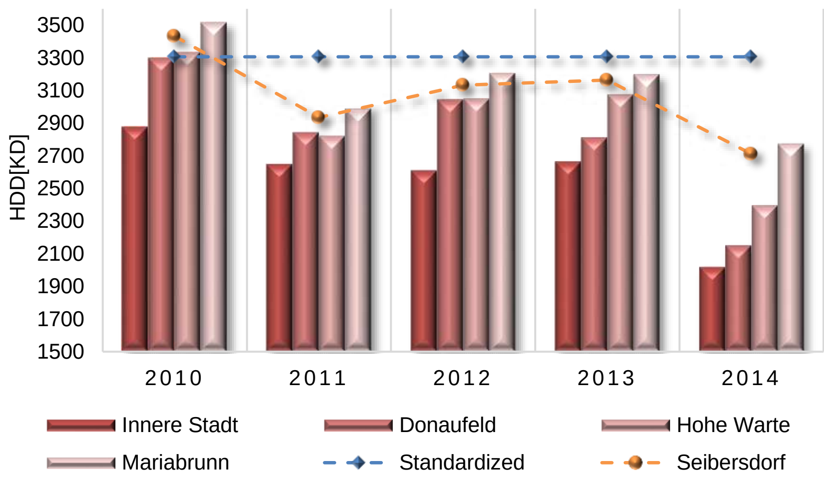

Figure 3-10 Heating degree days

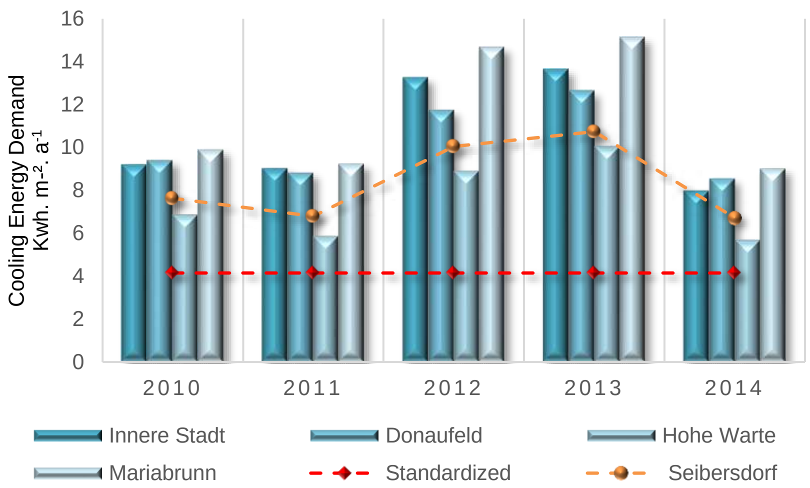

Figure 3-11 Spatial and temporal variance for mean annual cooling demand over five years periods for AB

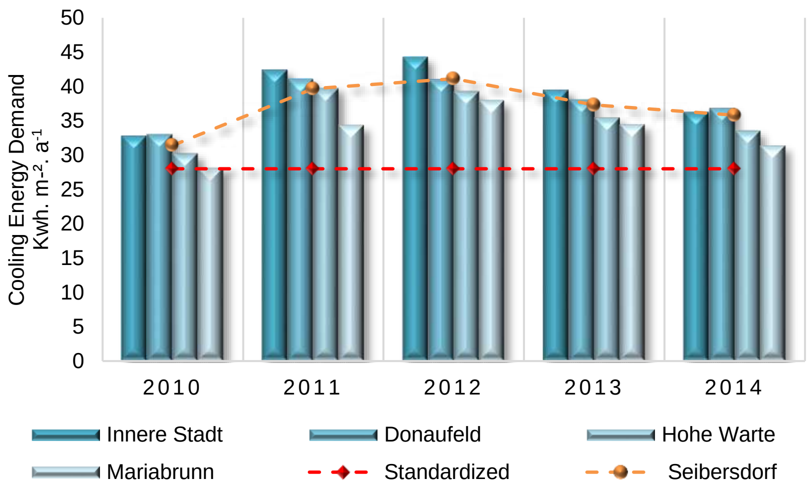

Figure 3-12 Spatial and temporal variance for mean annual cooling demand over five years periods for OF

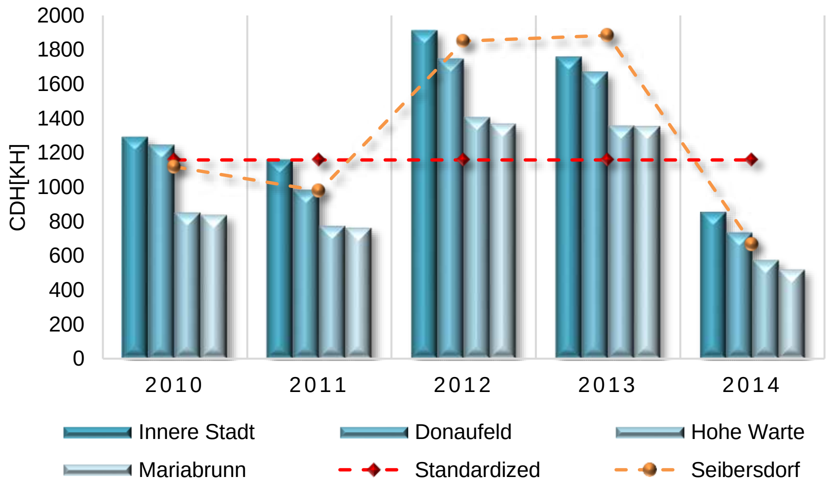

Figure 3-13 Cooling degree hours

3.5 The Representation of Urban Climate

Additional weather files were prepared, in which simulated urban values for air temperature and relative humidity were used. Since the Urban weather generator used in this thesis to transform the rural weather into urban provides no updated values of the solar radiation and wind speed, their observed urban values were used in order to control their influence in simulation results and to be able to evaluate the UWG performance in estimating the temperature and relative humidity. Two sites were identified as reference stations for the UWG, Seibersdorf and Mariabrunn.

3.5.1 Urban central location (Innere Stadt)

The Tables 3-6 to 3-9 quantify building simulation results in terms of relative differences in simulated energy demand for each building between results derived from the modeled and observed urban weather data. As can be seen, the UWG estimation satisfactory fit the results in the heating period and can reduce the discrepancies between rural and urban to near zero (Figures 3-14 to 3-18). The results show that the differences between the simulation results based on standardized weather and urban measured weather (Innere Stadt) in heating demand for the apartment block (min 9.2 max 31.6 aver 18.5) $kWhm^{-2}a^{-1}$ will be reduced to (min 0 max 0.5 aver 0.3) $kWhm^{-2}a^{-1}$. Whereas the differences in heating demand estimation for the office building will be reduced from (min 1.4 max 9.9 aver 5.4) $kWhm^{-2}a^{-1}$ to (min 0 max 0.3 aver 0.18) $kWhm^{-2}a^{-1}$when using UWG with the weather from Seibersdorf as input. And reduced again to (min 0 max 0.37 aver 0.13) $kWhm^{-2}a^{-1}$ when using the UWG with the weather from Mariabrunn as input. The heating degree days for the simulated urban weather provide a second proof that the UWG can estimate the urban temperature in the heating period. The calculate HDDs from the modeled and measured weather are identical (Figure 3-16). The deviation in heating demand between the results based on the modeled weather and the observation for both buildings for the years from 2010 to 2014 is rather small in the range of 0-3% (0-0.5 $kWhm^{-2}a^{-1}$) (Figure 3-17 and 3-18).

The Figures 3-19 to 3-23 show that the model accuracy was less during the cooling period when using introducing the weather from Seibersdorf as input in the UWG, UWG1/IS difference (aver 2.0) $kWhm^{-2}a^{-1}$. Whereas, the UWG estimation satisfactory fit the results in the cooling period when introducing the weather from Mariabrunn as input and can reduce the discrepancies to (aver 0.7) $kWhm^{-2}a^{-1}$.

The definition of a rural reference site is a one located near the research area but out of the metropolitan region and not affected by geographic elements such as valleys and water features (Oke 2006). Bearing in mind that, the ideal rural reference site for the UWG has an upwind location and has a night temperature difference for each month of the year (Street et al. 2013). To examine the suitability of Seibersdorf as a rural site used for the UWG. The temperature differences between Seibersdorf and Innere Stadt in 2013 were analyzed. the T rural-urban (maximum)= 11.1°C occurs on January 26, 2013 at 22:00 and the annual average T rural-urban (maximum) = 1.3°C. Figure 3-25 highlights that Seibersdorf has cooling degree hours very similar to the urban areas. Generally, the microclimate models used to generate urban data from rural weather data tend to raise the input temperature. Since the urban area and Seibersdorf experience a similar climate in summer, the model causes an additional rise in temperature results in EPW files that significantly overestimate the cooling demand.

The locations Seibersdorf and Mariabrunn have similar geometric properties and different geographic locations (Table 3-10). Analyzing the temperature observed at the low-density location Mariabrunn, the temperature differences compared to urban locations are significant in both winter and summer. The T rural-urban (maximum)= 12.5°C occurs on December 25, 2013 at 04:00 and the annual average T rural-urban (maximum) = 1.7°C. Like the typical UHI effect, the temperature differences are relatively small during the day and a maximum at night. Figure 3-24 and 3-25 highlight that the location Mariabrunn has a considerable difference in both heating degree days and cooling degree hours. Hence using the weather data form Mariabrunn as input in the UWG produced more accurate results.

The Figures 3-15 and 3-20 show that the UWG works better with Mariabrunn as input which presents an ideal reference site with maximum night temperature difference for every month of the year. The standardized to urban weather (Innere Stadt) differences in heating demand for the office building (min 1.4 max 9.9 aver 5.4) $kWhm^{-2}a^{-1}$ will be reduced to (min 0 max 0.3 aver 0.18) $kWhm^{-2}a^{-1}$, and to (min 0 max 0.37 aver 0.13) $kWhm^{-2}a^{-1}$ once using Seibersdorf and Mariabrunn respectively. The difference in cooling demand prediction of the office building will be reduced from (min 4.8 max 16.3 aver 11) $kWhm^{-2}a^{-1}$ to (min 0.7 max 3.2 aver 2) $kWhm^{-2}a^{-1}$ and (min 0.09 max 2.1 aver 0.9) $kWhm^{-2}a^{-1}$ once using Seibersdorf and Mariabrunn respectively. The comparison between Seibersdorf and Mariabrunn shows that the reference site must confirm the definition of rural and meet the requirements of the ideal UWG`s reference site otherwise this will probably lead to worse results. Figure 3-26 and 3-27 present the percentage differences in mean annual heating and cooling demand for OF in all urban locations compared to standardized case. These results suggest that methods for generating urban weather files from a rural station and account for the site-specific microclimatic condition have utility in building performance simulation.

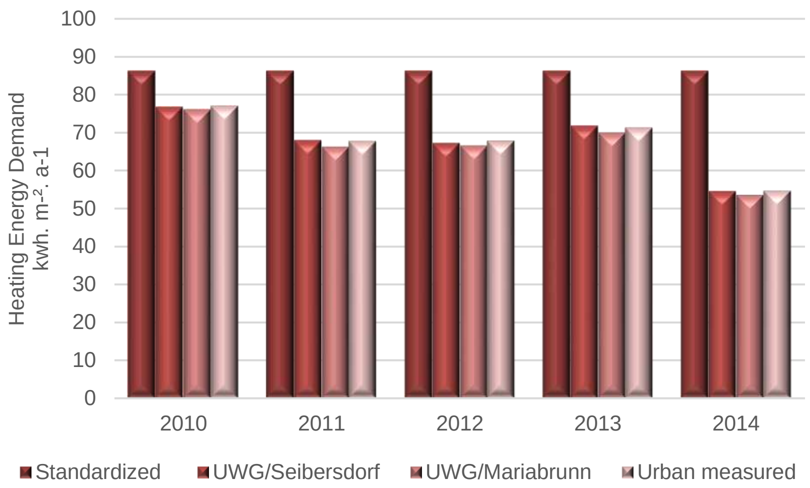

Figure 3-14 Heating demand for the apartment block using standardized, UWG-Seibersdorf, UWG-Mariabrunn compared to Innere Stadt observed weather

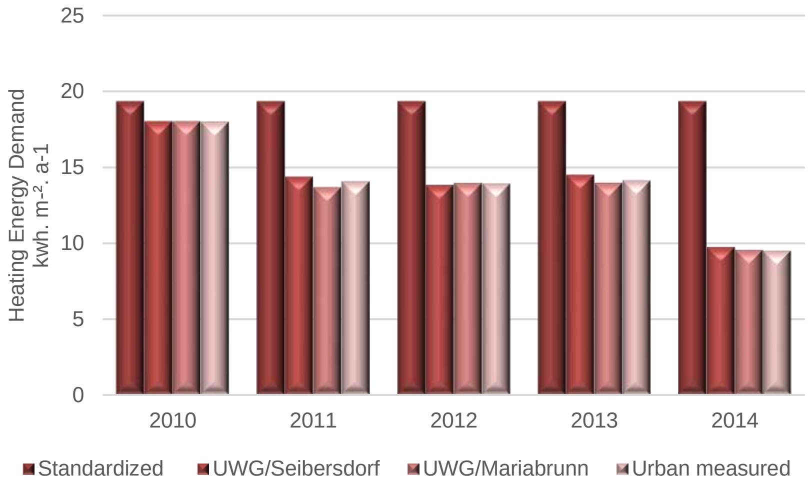

Figure 3-15 Heating demand for the office building using standardized, UWG-Seibersdorf, UWG-Mariabrunn compared to Innere Stadt observed weather

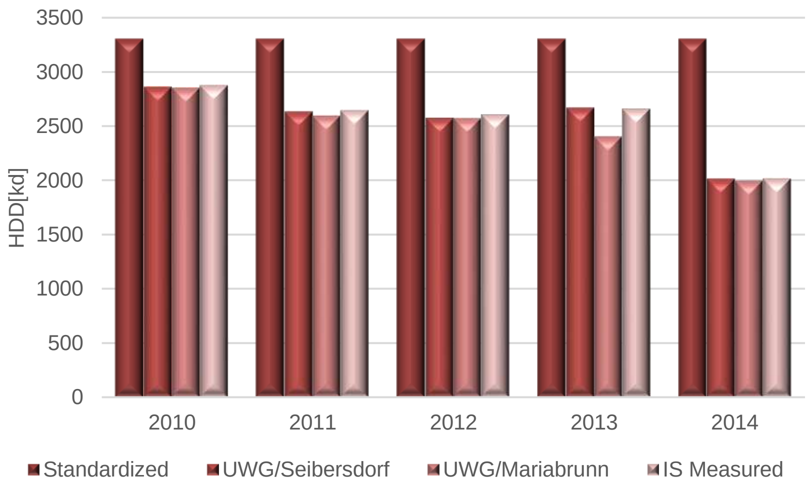

Figure 3-16 Heating degree days

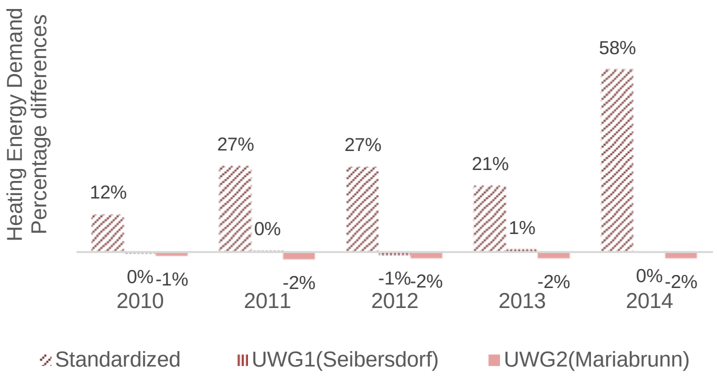

Figure 3-17 Percentage differences in mean annual heating demand for AB compared to Innere stadt

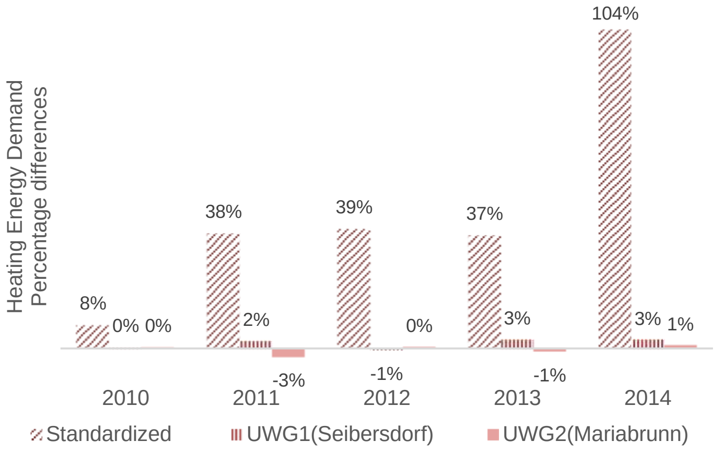

Figure 3-18 Percentage differences in mean annual heating demand for OF compared to Innere stadt

Table 3-6 Heatind demand for AB (kwhm^{-2}a^{-1}). Percentage difference calculated compared to results with the observed IS urban weather data. UWG1(Seibersdorf) and UWG2(Mariabrunn).

year	ST	SD	IS	UWG1	UWG2	ST/IS	UWG1/IS	UWG2/IS
2010	86.19	85.62	76.99	76.7	76.05	12%	0%	-1%
2011		76.87	67.73	67.96	66.21	27%	0%	-2%
2012		75.05	67.83	67.24	66.56	27%	-1%	-2%
2013		79.96	71.23	71.73	69.87	21%	1%	-2%
2014		63.37	54.61	54.58	53.57	58%	0%	-2%

Table 3-7 Heatind demand for OF (kwhm^{-2}a^{-1}). Percentage difference calculated compared to results with the observed IS urban weather data.

year	ST	SD	IS	UWG1	UWG2	ST/IS	UWG1/IS	UWG2/IS
2010	19.34	18.9	17.98	18.02	18.02	8%	0%	0%
2011		16.47	14.06	14.38	13.69	38%	2%	-3%
2012		14.76	13.91	13.84	13.96	39%	-1%	0%
2013		16.35	14.12	14.5	13.98	37%	3%	-1%
2014		11.41	9.48	9.73	9.56	104%	3%	1%

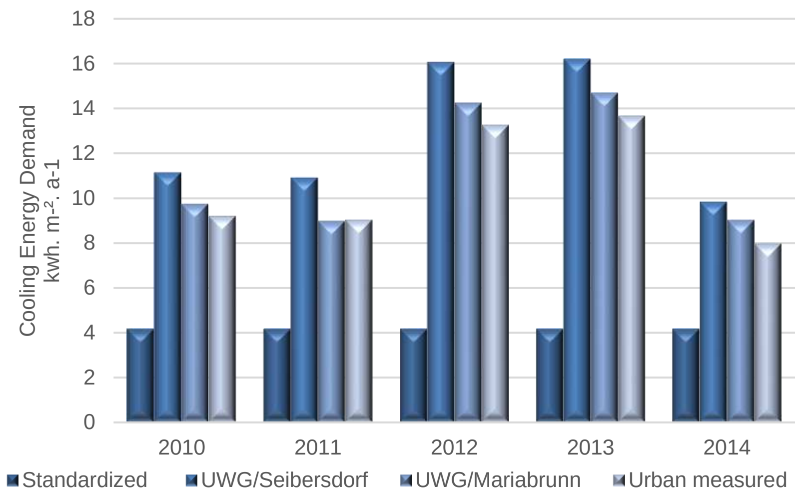

Figure 3-19 Cooling demand for the apartment block using standardized, UWG-Seibersdorf, UWG-Mariabrunn compared to Innere Stadt observed weather

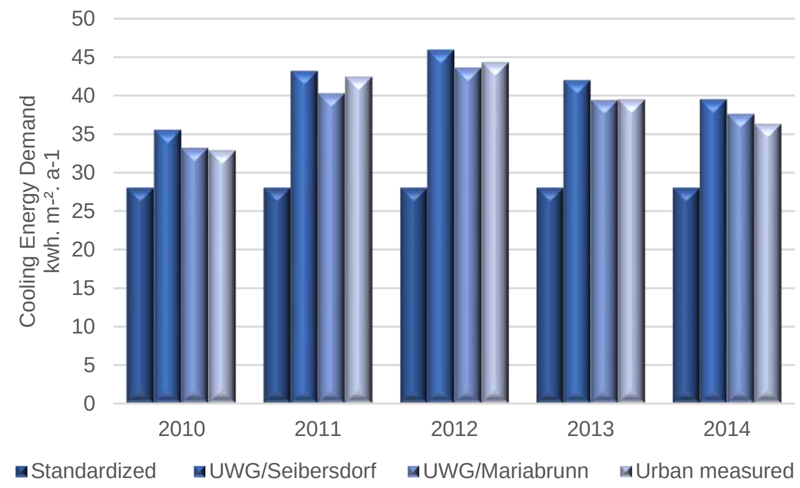

Figure 3-20 Cooling demand for the office building using standardized, UWG-Seibersdorf, UWG-Mariabrunn compared to Innere Stadt observed weather

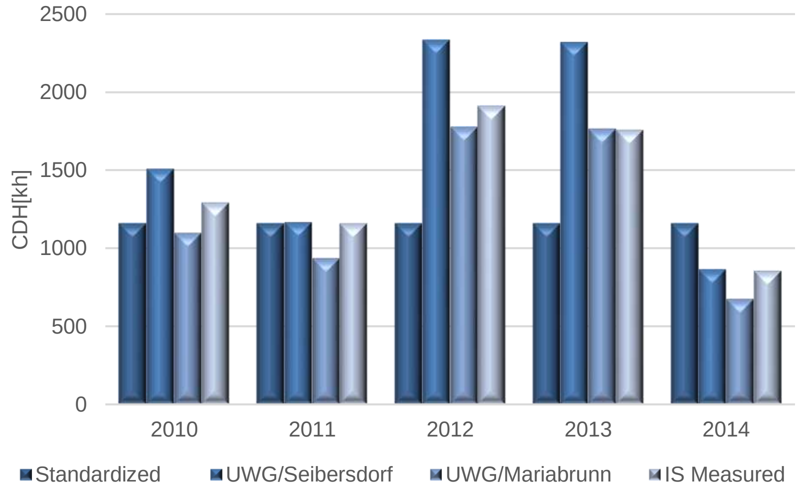

Figure 3-21 Cooling degree hours

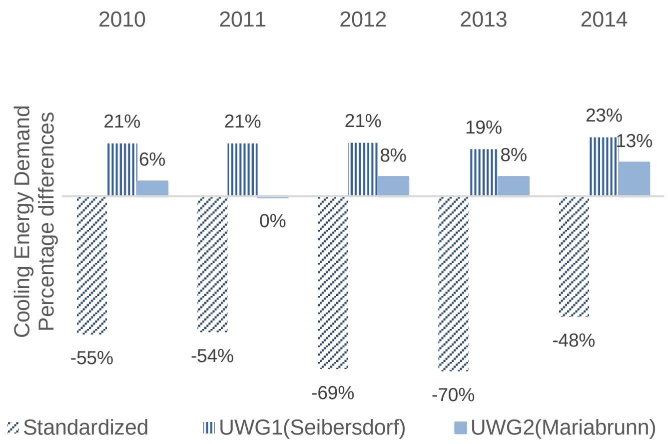

Figure 3-22 Percentage differences in mean annual cooling demand for AB compared to Innere Stadt

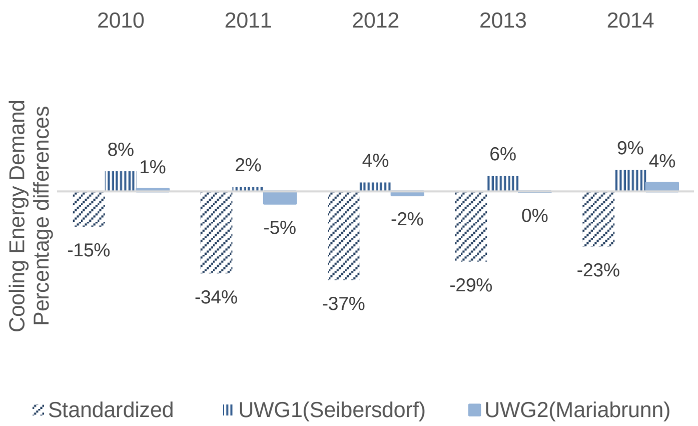

Figure 3-23 Percentage differences in mean annual cooling demand for OF compared to Innere Stadt

Table 3-8 Cooling demand for AB (kwhm^{-2}a^{-1}). Percentage difference calculated compared to results with IS urban weather data

year	ST	SD	IS	UWG1	UWG2	ST/IS	UWG1/IS	UWG2/IS
2010	4.15	7.63	9.2	11.13	9.74	-55%	21%	6%
2011		6.8	9.02	10.91	8.98	-54%	21%	0%
2012		10.05	13.25	16.06	14.25	-69%	21%	8%
2013		10.74	13.65	16.2	14.69	-70%	19%	8%
2014		6.72	7.97	9.83	9.03	-48%	23%	13%

Table 3-9 Cooling demand for OF (kwhm^{-2}a^{-1}). Percentage difference calculated compared to results with IS urban weather data

year	ST	SD	IS	UWG1	UWG2	ST/IS	UWG1/IS	UWG2/IS
2010	28.01	31.42	32.8	35.52	33.15	-15%	8%	1%
2011		39.7	42.4	43.19	40.24	-34%	2%	-5%
2012		41.13	44.27	45.92	43.54	-37%	4%	-2%
2013		37.33	39.44	41.95	39.35	-29%	6%	0%
2014		35.8	36.26	39.48	37.57	-23%	9%	4%

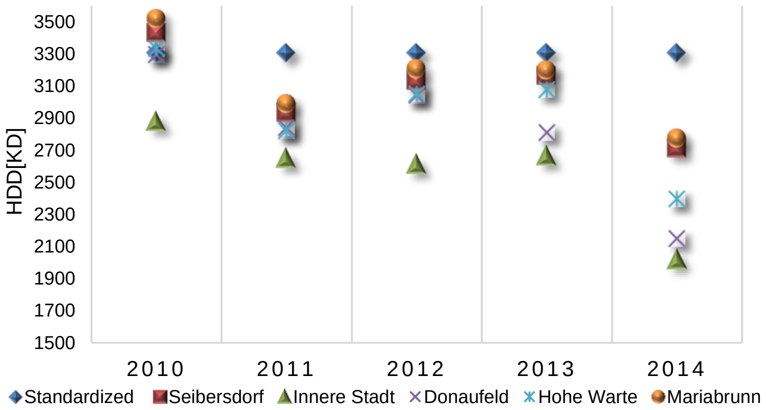

Figure 3-24 Heating degree days

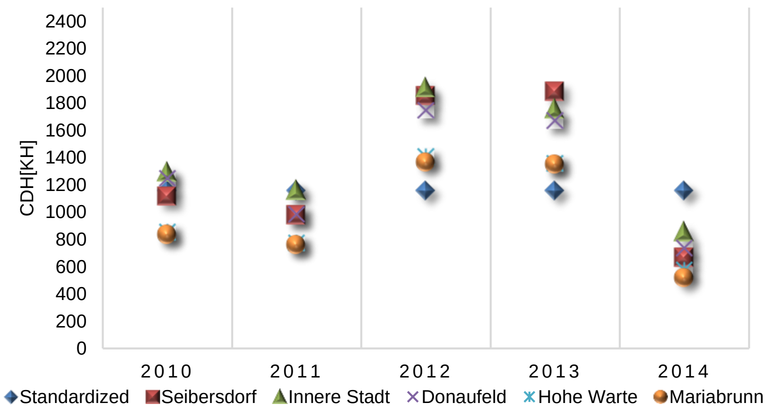

Figure 3-25 Cooing degree hours

Table 3 -10 Geometry properties for Seibersdorf and Mariabrunn

Station	Seibersdorf	Mariabrunn
Average building height (m)	5.3	10.1
Site coverage ratio	0.08	0.04
Facade-to-site ratio	0.09	0.07
Tree coverage	0.83	0.86
Sensible anthropogenic heat ($W.m^{-2}$)	0.08	0
Location to city center	Southeast	West

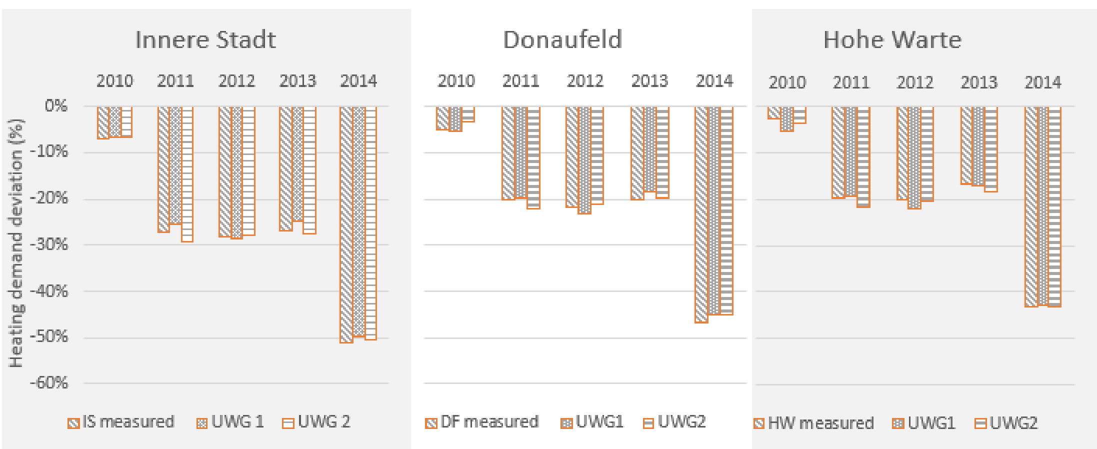

Figure 3-26 Percentage differences in mean annual heating demand for OF compared to standardized case

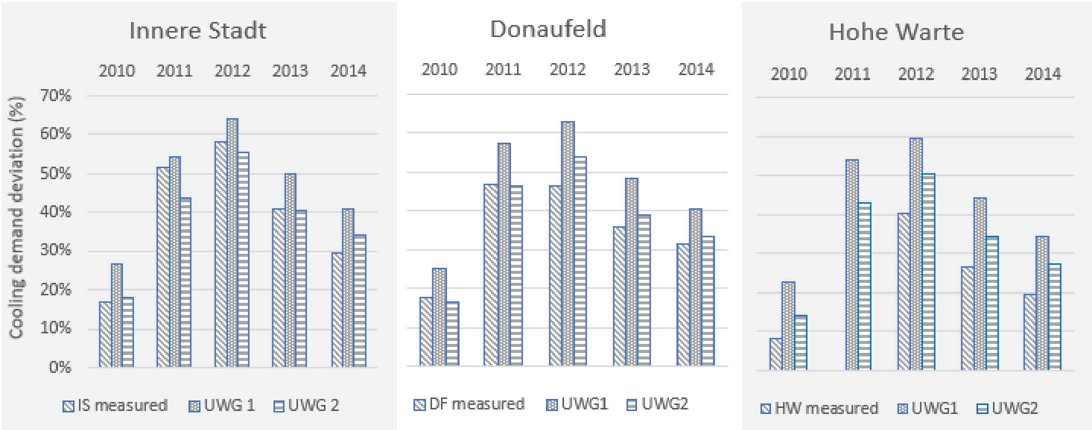

Figure 3-27 Percentage differences in mean annual cooling demand for OF compared to standardized case

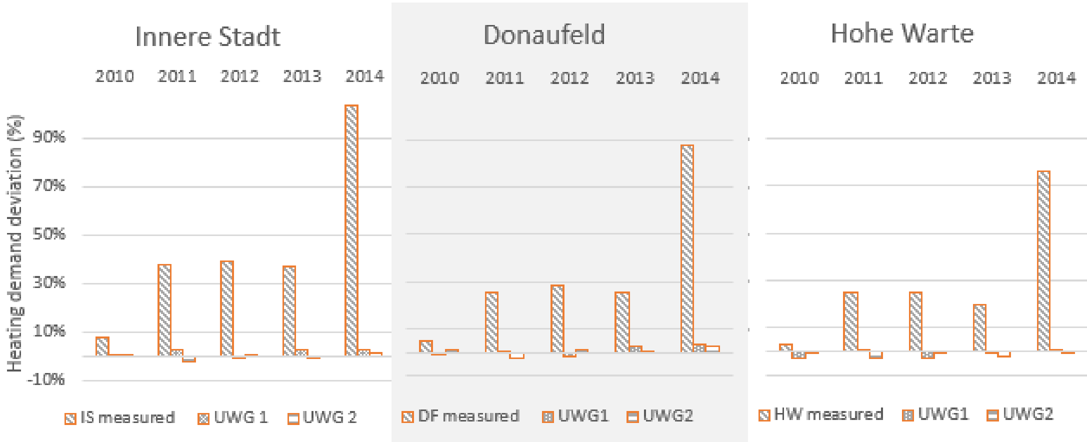

Figure 3-28 Percentage differences in mean annual heating demand for OF compared to urban measured case

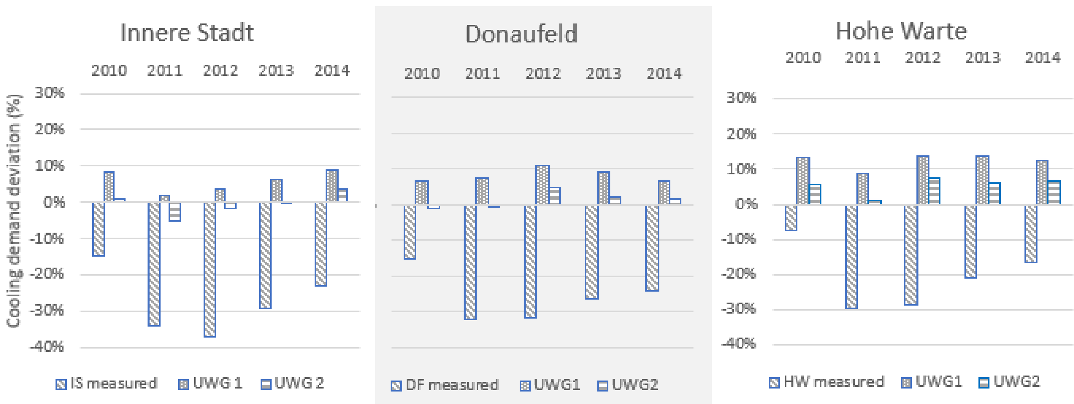

Figure 3-29 Percentage differences in mean annual cooling demand for OF compared to urban measured case

3.5.2 Suburban locations (Donaufeld and Hohe Warte)

The model performed similarly in suburban locations as Donaufeld (Figure 3-30 and 3-31). The UWG reduce the deviations in heating demand between the standardized and observation at Donaufeld to 1-3 % (min 0.1 max 0.4 aver 0.2) $kWhm^{-2}a^{-1}$ overestimation between modeled and observation. The deviations in cooling demand between the standardized case and urban observation reduced to 0-5% (min 0 max 2 aver 0.7) $kWhm^{-2}a^{-1}$ overestimation. Which means that the estimation of the temperature and relative humidity in the heating and cooling seasons in the location was satisfactory. At Hohe Warte, the UWG reduce the deviations in heating demand between the standardized and observation to 0-3 % (min 0.0 max 0.5 aver 0.2) $kWhm^{-2}a^{-1}$ between modeled and observation (Figure 3-32). The cooling demand variations replaced by 9-14% (min 3.4 max 5.4 aver 4.4) $kWhm^{-2}a^{-1}$ overestimation (Figure 3-33). The estimation of the temperature and relative humidity in the heating season in Hohe Warte is satisfactory. However, the UWG slightly overestimated the temperature in the summer which in turn lead to overestimation in the cooling demand.

The urban site is defined as a site with dense buildings, few or no trees, land cover mostly paved, no major parks or water features exist within a 500 m radius of the station, concrete or brick construction materials and the topography is flat with few variations and no major rises in elevation (Oke 2006). The station Hohe Warte does not confirm the definition of the urban location has a cold and humid local climate and influenced by the higher altitude and the proximity to Vienna woods. Since the urban area Hohe Warte and the reference station Mariabrunn experience a similar climate in summer (Figure 3-25), the model causes an additional rise in temperature results in EPW files that slightly overestimate the cooling demand. This suggests that applying urban microclimates generators to the unsuitable station works against the expected results of reducing the energy demand discrepancy. Analytic models of the urban microclimates require enough urban morphological data, and they are very flexible in their ability to describe an urban area and the physical process that accrues. Figure 3-26 and Figure 3-27 demonstrate that the differences in the energy demand of buildings simulated by standardized and site-specific weather files are considerable and the UWG reduces these discrepancies significantly. The UWG performs similarly in different locations such as Donaufeld and Hohe Warte which validate its robustness and reliability.

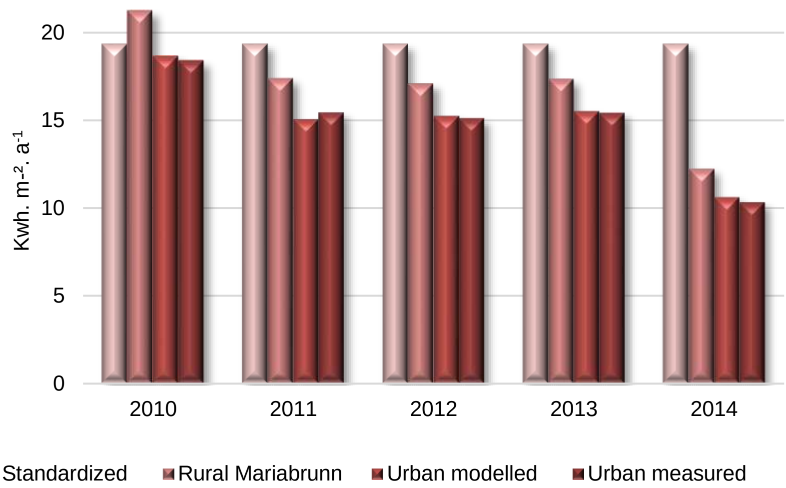

Figure 3-30 Heating demand for the office building using Mariabrunn, Donaufeld measured and UWG modeled weather files

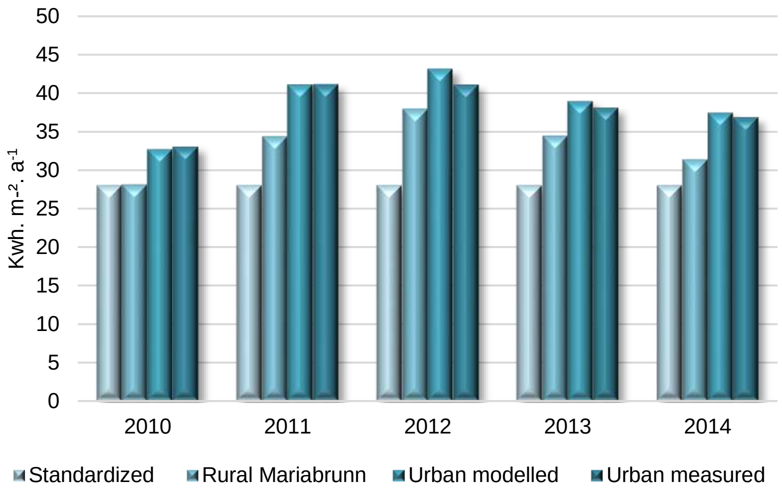

Figure 3-31 Cooling demand for the office building using Mariabrunn, Donaufeld measured and UWG modeled weather files

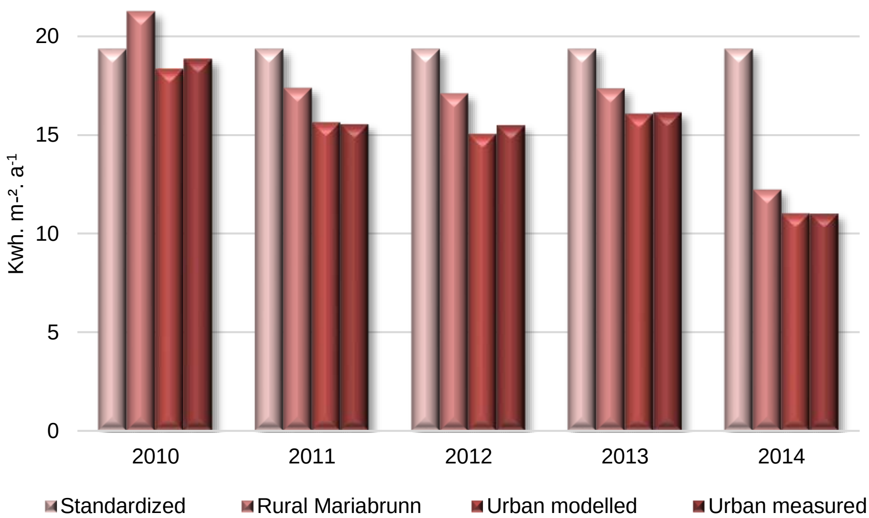

Figure 3-32 Heating demand for the office building using Mariabrunn, Hohe Warte measured and UWG modeled weather files

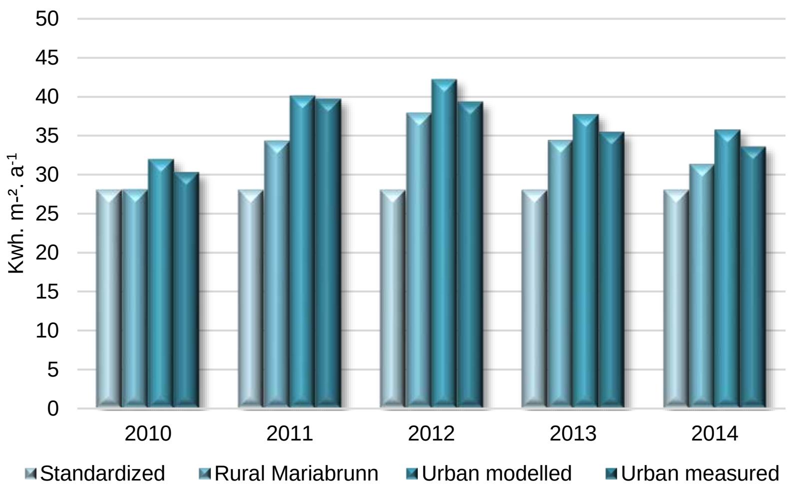

Figure 3-33 Cooling demand for the office building using Mariabrunn, Hohe Warte measured and UWG modeled weather files

3.5.3 Wind speed and global solar radiation

Changes in all four-weather elements directly affect the energy demand of buildings. The wind directly affects exterior surface convection, Infiltration, and natural ventilation in buildings. To examine the impact of the difference between rural and urban wind speed in the simulated energy demand each building was additionally simulated with weather files containing the simulated temperature, the simulated relative humidity, the urban measured global solar radiation, and the rural wind speed. Next, the results were compared to those which utilizes the urban wind (Figure 3-34 and 3-35). The results imply that the significant decrease of wind speed in winter (Figure 3-4); 30-35% (min 0.9 max 1.2 aver 1) ms^{-1} translated into a rather small decrease in heating demand 0-1% (min 0 max 0.16 aver 0.12) $kWhm^{-2}a^{-1}$. The significant decrease of wind speed in summer; 42-50% (min 1.1 max 1.4 aver 1.3) ms^{-1} translated into a rather small increase in cooling demand for the office building 0-1% (min0.17 max 0.25 aver 0.22) $kWhm^{-2}a^{-1}$.

A similar investigation was conducted to determine the impact of the difference between rural to urban global solar radiation. The small variation (decrease) of global solar radiation 3-9% (min 0.4 max1.3 aver 0.96) wm^2 and 0-2% (min 0.3 max 1.5 aver 0.6) wm^2 in winter and summer (Figure 3-3), translated into remarkable variations (increase) in the range of 0-4%(min 0 max 0.54 aver 0.4) $kWhm^{-2}a^{-1}$ in heating demand and a decrease 0-1% (min 0.28 max 0.64 aver 0.5) $kWhm^{-2}a^{-1}$ in cooling demand (figur3-36 and 3-37). These results show that the difference in global solar radiation has more significant influences on energy demands.

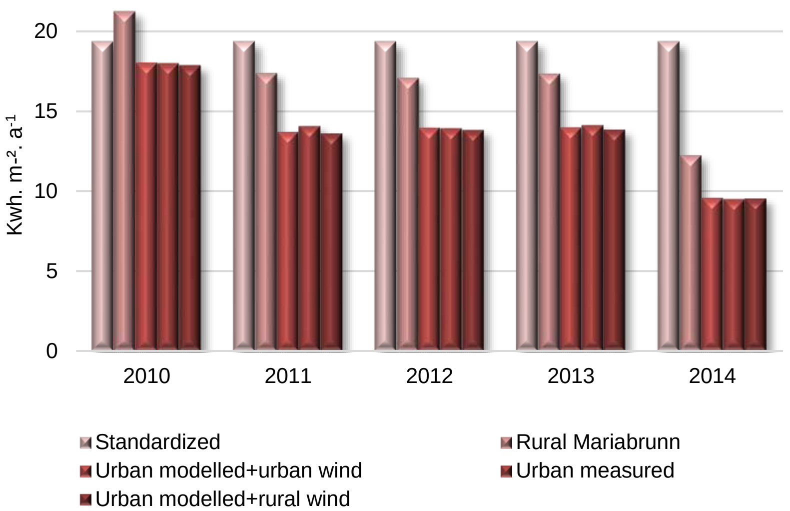

Figure 3-34 The influence of the difference between urban and rural wind speed on heating demand, OF/ IS.

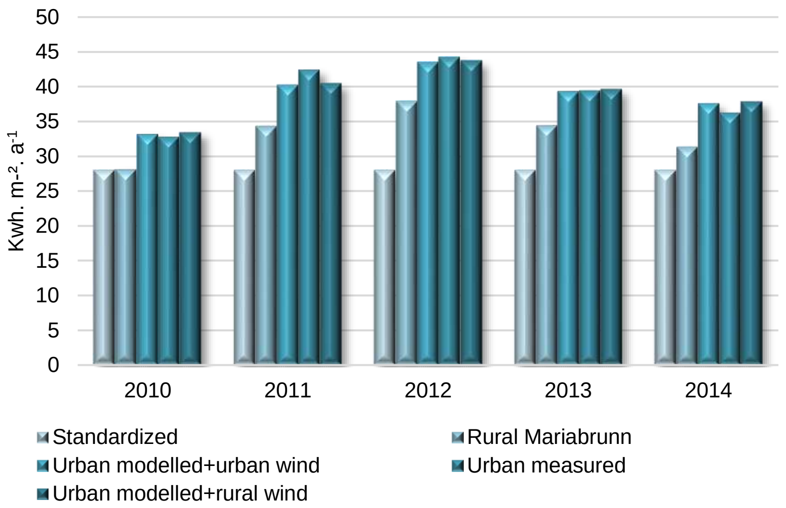

Figure 3-35 The influence of the difference between urban and rural wind speed on cooling demand, OF/ IS.

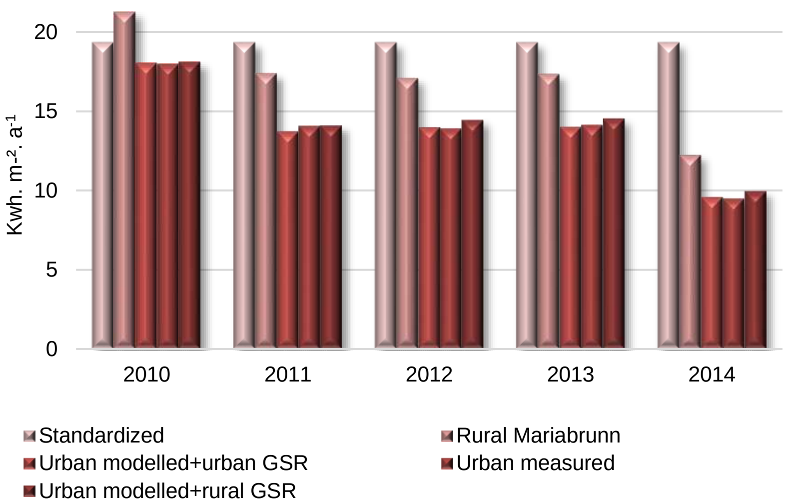

Figure 3-36 The influence of the difference between urban and rural global solar radiation on heating demand, OF/ IS.

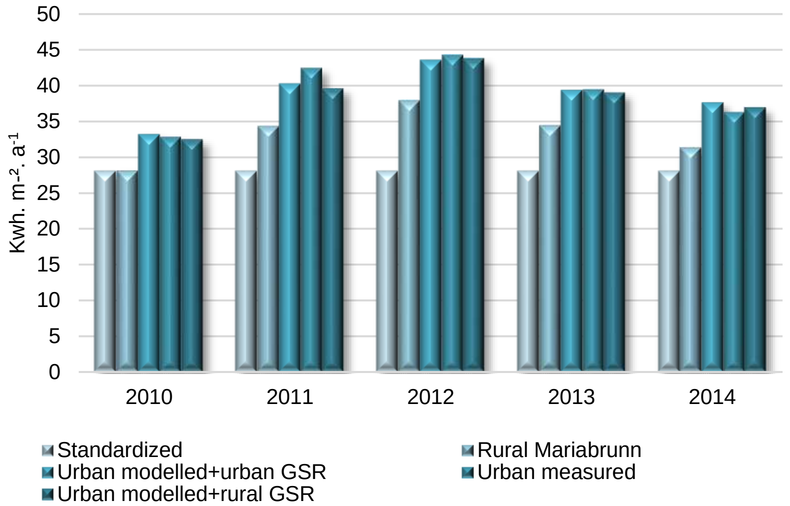

Figure 3-37 The influence of the difference between urban and rural global solar radiation on cooling demand, OF/ IS

Finally, each building was simulated with additionally weather file containing only the result of the urban weather generator to represent the best possible results achieved by using only this simple method. Since the UWG provides no updated values of global solar radiation and wind speed the measured values at the reference station Mariabrunn were used. Figure 3-38 and Figure 3-39 compare the simulation results when using urban (Innere Stadt) and rural (Mariabrunn) wind speed and global solar radiation (UWG only). The results are almost identical. The lower rural wind speed produces lower heating demand while the lower rural global solar radiation produces higher heating demand. These two errors cancel each other, and the heating demand remains almost the same. These results suggest that if we only have weather data from Mariabrunn, we would be able to simulate the thermal performance of buildings in Innere Stadt in a satisfactory way.

Despite, the variation of global solar radiation is rather small across the observed areas (Figure 3-3). The location Donaufeld displays the maximum differences (increase) of the global solar radiation compare to the rural Mariabrunn (min 0.4 max 2.6 aver 1.6) wm^2 and (min1.3 max 6 aver 3.4) wm^2 in winter and summer, which cause significant discrepancies in energy demand when we use the UWG (min 0.7 max 1.1 aver 0.8) $kWhm^{-2}a^{-1}$ overestimated heating and (min 0.7 max 2.7 and aver 1.6) $kWhm^{-2}a^{-1}$ underpredicted cooling (Figure 3-40 and 3-41). This might be due to the higher fraction of the area of the windows of this office building, 39 % compared to 15 % in the apartment block. The impacts of the urban to the rural difference in global solar radiation on fenestration heat gain and the exterior surfaces heat balance cannot be neglected which implies that alternative techniques incorporating more detailed analysis may be needed for effective energy performance simulation.

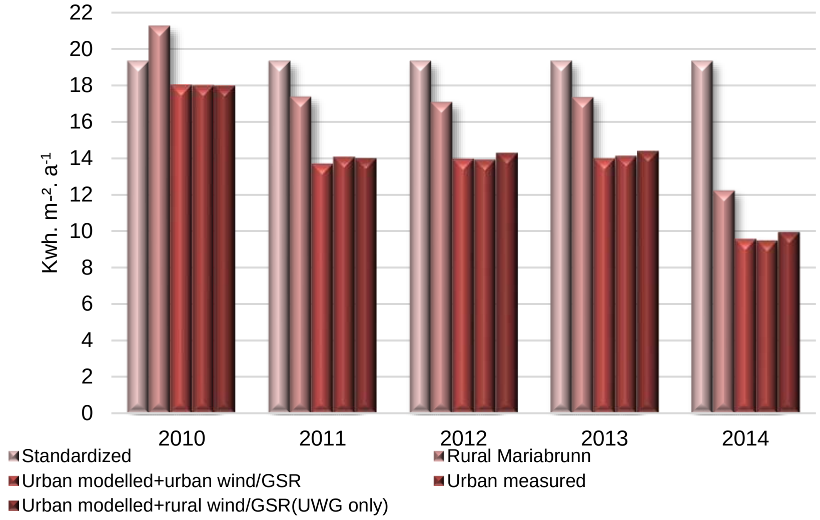

Figure 3-38 The influence of the difference between urban and rural wind speed and global solar radiation on heating demand, OF/ IS.

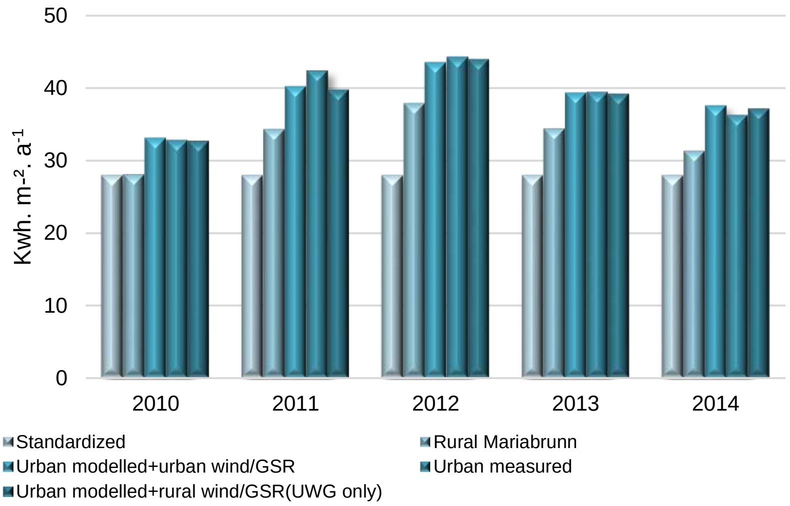

Figure 3-39 The influence of the difference between urban and rural wind speed and global solar radiation on cooling demand, OF/ IS.

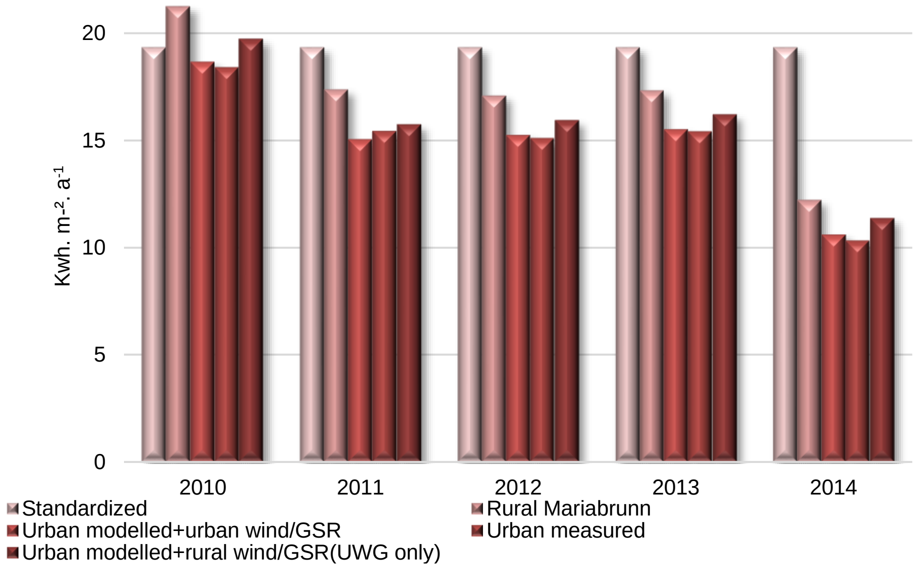

Figure 3-40 The influence of the difference between urban and rural wind speed and global solar radiation on heating demand, OF/ DF.

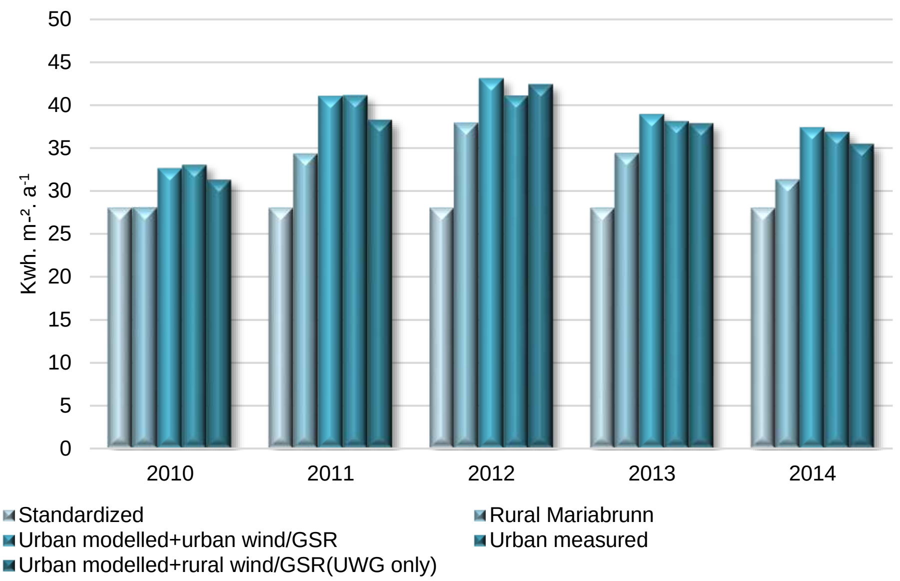

Figure 3-41 The influence of the difference between urban and rural wind speed and global solar radiation on cooling demand, OF/ DF.

4 CONCLUSION

Changes in urban microclimates and corresponding higher air temperature have consequences on issues such as thermal comfort, mortality rate, air quality and energy consumptions of buildings. Thereby, the study of urban microclimate is highly relevant. The results of the current research demonstrate that there are significant seasonal discrepancies regarding the observed weather elements such as air temperature, absolute humidity, solar radiation, and wind speed as comparing the weather data collected at the urban stations and to the standard weather file usually used for building energy simulations in Vienna. Moreover, the current study investigates the impact of site-specific microclimatic conditions on the building's energy performance. The results suggest that the usage of location-independent weather files such as the standard weather files for building performance simulation can result in unrealistic energy demand estimations. As these data are not reliable and do not describe the actual climate in each part of the city, and they are typically based on long ago measurements. Thereby, the weather data provided by a climate database based on more recent years may be more reliable alternatives. However, recent measurements from reference stations located outside the urban area neglect the significant UHI effects and the microclimatic circumstances in the site of the building. The use of urban weather generators to estimate the urban effects in a city from meteorological information measured in an operational weather station outside the city can work around this bias. Each type of building presents significant energy demand variations when using site-specific weather. Therefore, not considering the microclimate in the prediction of energy demand could lead to serious consequences in terms of building overdesign resulting in materials waste or under design resulting in energy waste. Therefore, buildings designers should adjust the minimum construction requirements to fit the local microclimate conditions to achieve optimum energy and materials consumption.

This research proofed the applicability of generating urban weather files from measurements at a weather station located out of the metropolitan area and highlighted the weight of accounting for the significant difference between rural and urban locations. The outcome of this assessment contributes to proof that spending more time and effort on the representation of urban microclimate in the thermal energy simulation of the buildings is worthy and will lead to more reliable and accurate results. The evaluation of the UWG highlights that the current version of the UWG performs well in Vienna in urban and suburban locations in which the morphology is relatively homogeneous, and the vegetation is scarce. In conclusion, the use of UWG is recommended for the fast generation of hourly files that account for urban effects, and the following points should be taken into consideration:

- The reference weather station for the UWG can be one of the remote stations provided that it is not situated near urbanization and it is not significantly influenced by the existence of large water features or by the significant difference in topography. Reference sites upwind of the city produce the best results.
- The ideal reference station exhibits significant differences in temperature as compared to the urban stations for each month of the year.
- The comprehensive data concerning urban morphology is a necessity, which can be not accessible in all locations. In case there is not enough data to describe the urban morphology, do not apply this model.
- Applying urban microclimates models to the wrong suburban peripherical location with microclimate similar to the rural reference station will work against the expected results of reducing the energy demand discrepancy.
- Buildings´ thermal performance is significantly influenced by all four weather parameters which suggest that alternative or additional techniques incorporating the global solar radiation are necessary to improve simulation predictions.

The results of this study seemed to be promising and in line with expectations. However, additional future research efforts are required. Some new insights and possible trends might appear if the same study is performed for a much longer period for more buildings at more locations. This could be useful for a better understanding of the microclimate features that have the biggest impacts on the thermal performance of different types of buildings. Moreover, the wind sheltering effect usually decreases the wind speed intensively in urban locations compared to an open area. According to the stations' measurements, the wind speed is constantly and considerably higher at Hohe Warte and Innere Stadt. The higher measurement location could be the reason for the record of these higher speeds. Therefore, the unified and revised measurements` heights are crucial for future microclimate analysis. According to the stations' measurements, the location Donaufeld displays the maximum differences (increase) in the global solar radiation compared to the rural station Mariabrunn, which causes significant discrepancies in energy demand when using the UWG. Future investigations and measurements to confirm the existence of this difference between urban locations in global solar radiation are required. As the current version of UWG provides no update to the wind speed and global solar radiation; additional or alternative techniques incorporating more detailed analysis may be needed for effective energy performance simulation.

A recurrent challenge about the urban microclimate and urban heat island is the identification and evaluating of the possible mitigation measures. The adjustment of surface thermal properties, the intensification of the vegetated areas and the decrease of anthropogenic heat emission are believed to influence the urban microclimatic conditions and can recover the urban heat island consequences. The flexibility of the UWG in the description of the urban morphology, geometry, and surface materials and its ability in the simulation of the physical processes that happen, make it capable to evaluate the effect of the potential mitigation measure by changing the related variables. Moreover, the UWG is available as a stand-alone tool and will be available as a plug-in for other software to expand its capabilities to parametrically test urban design strategies. This enables urban designers to parametrically test built densities and vegetation for master planning. Urban planners can evaluate zoning regulations such as buildings heights and land use as well as policies for traffic intensity and cool roof with energy and thermal implications of these interventions.

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7 APPENDIX

A. Construction elements for research buildings

Table 7-1 Apartment block construction elements

Element	Material	Total Width d[m]	Thickness [m]	Thermal conductivity [$W.m^{-1}. K^{-1}$]	Density [$Kg.m^{-3}$]	Specific Heat [$J. Kg^{-1}. K^{-1}$]
External walls U = 1.53 $W.m^{-2}. K^{-1}$	Outside plaster	0.5	0.025	1.2	1600	1000
	Brick		0.45	1.02	1800	850
	Inside plaster		0.025	1.2	1600	1000
Internal thin walls	Inside plaster	0.19	0.02	1.2	1600	1000
	Brick		0.15	1.02	1800	850
	Inside plaster		0.02	1.2	1600	1000
Internal thick walls	Inside plaster	0.49	0.02	1.2	1600	1000
	Brick_		0.45	1.02	1800	850
	Inside plaster		0.02	1.2	1600	1000
Floors to basement U = 1.3 $W.m^{-2}. K^{-1}$	Arched Ceiling (Deckengewoelbe)	0.465	0.3	0.6	1800	850
	Sand		0.15	1.8	1500	840
	Natural Stone		0.015	2.5	2224	771
Internal Floors U = 0.62 $W.m^{-2}. K^{-1}$	Parquet	0.357	0,024	0.15	740	1600
	Sand		0.08	1.4	1500	840
	Ceiling formwork (schalung)		0.024	0.15	700	1760
	Beam ceiling (Tramdecke)		0.18	0.205	700	1760
	Ceiling formwork (schalung)		0.024	0.15	700	1760
	Inside plaster		0.025	1.2	1600	1000
Ceiling upper floor U = 0.73 $W.m^{-2}. K^{-1}$	Brick Tiles	0.375	0.05	1.2	1800	850
	Sand		0.08	1.4	1500	840
	Ceiling (Dippelbaumdecke) 22cm		0.22	0.205	700	1760
	Inside plaster		0.025	1.2	1600	1000
Roof U = 1.26 $W.m^{-2}. K^{-1}$	Roof tiles	0.165	0.02	1	1800	850
	MOD Roof formwork (schalung)		0.12	0.205	700	1760
	Inside plaster		0.025	1.2	1600	1000
Windows U = 2.5$W.m^{-2}. K^{-1}$						

Table 7-2 Office building construction elements

Element	Material	Total Width d[m]	Thickness [m]	Thermal conductivity [$W.m^{-1}. K^{-1}$]	Density [$Kg.m^{-3}$]	Specific Heat [$J. Kg^{-1}. K^{-1}$]
External walls U = 0.39 $W.m^{-2}. K^{-1}$ U value=0.35 $W.m^{-2}. K^{-1}$	Outside plaster	0.26	0.015	1.2	1600	1000
	EPS		0.08	0.035	30	1450
	Concrete		0.15	1.95	2240	900
	Inside plaster		0.015	1.2	1600	1000
Internal walls	Inside plaster	0.20	0.025	1.2	1600	1000
	Reinforced concrete		0.15	2.4	2350	1000
	Inside plaster		0.025	1.2	1600	1000
Walls to ground U = 0.37 $W.m^{-2}. K^{-1}$ U value=0.40 $W.m^{-2}. K^{-1}$	Reinforced concrete	0.3842	0.30	2.4	2350	1000
	Bitumen waterproofing		0.004	0.22	3000	792
	XPS		0.08	0.033	30	1380
	PP Non woven filter cloth		0.0002	0.22	600	792
Floors to ground U = 0.37 $W.m^{-2}. K^{-1}$ U value=0.40 $W.m^{-2}. K^{-1}$	Heavyweight concrete	0.4324	0.2	1.95	2240	900
	PE		0.0002	0.5	980	1260
	EPS		0.08	0.035	30	1450
	Building Paper felt		0.0002	0.17	500	1500
	Sand blinding		0.15	1.3	2240	980
	PP Non woven filter cloth		0.0002	0.22	600	792
Floors to basement U = 0.39 $W.m^{-2}. K^{-1}$ U value=0.40 $W.m^{-2}. K^{-1}$	Cement screed	0.31	0.035	1	2000	1080
	Reinforced concrete		0.18	2.4	2350	1000
	EPS		0.08	0.035	30	1450
	Inside plaster		0.015	1.2	1600	1000
Internal Floors U = 0.87 $W.m^{-2}. K^{-1}$ U value=0.90 $W.m^{-2}. K^{-1}$	Cement screed	0.26	0.035	1	2000	1080
	EPS		0.03	0.035	30	1450
	Reinforced concrete		0.18	2.4	2350	1000
	Inside plaster		0.015	1.2	1600	1000
Roofs U = 0.2 $W.m^{-2}. K^{-1}$ U value=0.20 $W.m^{-2}. K^{-1}$	Natural Stone	0.32	0.011	2.5	2224	771
	Bituminous		0.004	0.22	3000	792
	EPS		0.14	0.035	30	1450
	Reinforced concrete		0.15	2.4	2350	1000
	Inside plaster		0.015	1.2	1600	1000
Windows U = 1.7 $W.m^{-2}. K^{-1}$ U value=1.7 $W.m^{-2}. K^{-1}$						