DIPLOMARBEIT

The Impact of Urban Microclimate Assumptions on Predictions of the Thermal Performance of Buildings

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ABSTRACT

Urban areas are dynamic and complex entities that are bound to be impacted by changes in climate. Recent studies have established that urban agglomerations encompass a number of different climate conditions that result in specific local microclimates. This paper aims to evaluate the impact of local urban microclimates on thermal performance of buildings. It analyzes and describes the magnitude of the discrepancies in energy demand as a function of location and building type over a certain period of time. More specifically, the energy demand required by three new constructions (family house, a multi-family apartment block building, and an office building) is simulated at three different locations within the city of Vienna, Austria, over a 5-year period of time (2008 to 2012) using TAS (Thermal Analysis Simulation Software). The local microclimates are described by the empirical weather data obtained from nearby meteorological stations. These stations were particularly chosen to be representative for different microclimates i.e. hilly green area, city downtown, and a flat, low altitude area. Climatic factors such as temperature, humidity, solar radiation, wind speed and direction were used to generate weather files compatible with TAS. Construction materials and internal conditions follow the current Austrian standards and stay constant during the simulations. The results point towards important fluctuations of energy demand that are consistent with the change in location, time, and building type. Local microclimate conditions and their impact on the simulated energy demand are analyzed and used to explain these fluctuations. Finally, one more simulation is performed for each type of building using a Vienna city standard weather file employed in current energy calculation (IWEC). The simulated results using local conditions are compared against the one obtained from the use of the standard weather file. It is concluded that local microclimates within an urban area have a significant impact on building' heating and cooling energy demands. Building designers, architects, building performance specialists as well as policy makers would greatly benefit from understanding and using local microclimate conditions when designing, simulating or approving future construction developments.

Keywords

microclimate, thermal performance, energy efficiency, simulation, prediction.

KURZFASSUNG

Städtische Gebiete sind dynamische und komplexe Einheiten, die durch Klimaveränderungen beeinflusst werden. Neue Studien haben nachgewiesen, dass städtische Agglomerationen eine Reihe von unterschiedlichen Klimabedingungen umfassen, die zu spezifischen lokalen Mikroklimaten führen. Diese Arbeit zielt darauf ab, die Auswirkungen der lokalen städtischen Mikroklimate auf die thermische Leistung von Gebäuden zu bewerten. Sie analysiert und beschreibt die Größenordnung der Abweichungen im Energiebedarf als Funktion von Standort und Gebäudetyp über einen bestimmten Zeitraum. Genauer gesagt wird der Energiebedarf von drei Neubauten (Familienhaus, Mehrfamilienhausgebäude und Bürogebäude) an drei verschiedenen Standorten innerhalb der Stadt Wien, Österreich, über einen Zeitraum von 5 Jahren (2008 bis 2012) mit Tas (Thermal Analysis Simulation Software) simuliert. Die lokalen Mikroklimate werden durch die empirischen Wetterdaten beschrieben, die von nahe gelegenen meteorologischen Stationen aufgezeichnet wurden. Diese Standorte wurden dahingehend ausgewählt, um für verschiedene Mikroklimate repräsentativ zu sein, d.h. hügelige grüne Fläche, Innenstadt und ein flaches Gebiet von geringer Höhenlage. Klimafaktoren wie Temperatur, Feuchtigkeit, Sonneneinstrahlung, Windgeschwindigkeit und Windrichtung wurden verwendet, um Wetterdateien zu erzeugen, die mit Tas kompatibel sind. Baustoffe und interne Bedingungen enstprechen den aktuellen österreichischen Normen und bleiben während der Simulationen konstant. Die Ergebnisse zeigen erhebliche Schwankungen des Energiebedarfs, abhängig von Standort, Zeit und Gebäudetyp. Lokale Mikroklima-Bedingungen und ihre Auswirkungen auf den simulierten Energiebedarf werden analysiert und herangezogen, diese Schwankungen zu erklären. Schließlich wird für jede Bauart eine weitere Simulation mit einer Wiener Standard-Wetterdatei, die in der aktuellen Energieberechnung (IWEC) eingesetzt wird, durchgeführt. Die simulierten Ergebnisse unter Verwendung empirischer lokaler Wetterdaten werden mit denen verglichen, die aus der Verwendung der Standard-Wetterdatei erhalten wurden. Es wird gefolgert, dass lokale Mikroklimate innerhalb eines städtischen Gebiets einen erheblichen Einfluss auf den Heiz- und Kälteenergiebedarf von Gebäuden haben. Gebäudedesigner, Architekten, Bauleistungsspezialisten sowie politische Entscheidungsträger würden bei der Gestaltung, Simulation oder Genehmigung zukünftiger Bauentwicklungen von dem Verständnis und der Anwendung lokaler Mikroklimabedingungen profitieren.

Schlüsselwörter

Mikroklima, Thermische Leistung, Energieeffizienz, Simulation, Prognose.

CONTENTS

1 INTRODUCTION

1.1 Objective

In early design stages, architects employ thermal simulations in order to determine the optimal solution for their design. Other professionals use simulations for benchmarking design. There are several input parameters used in simulations that have an important impact on the quality of predictions for the thermal performance of a building. One should consider here: external conditions, internal conditions (occupancy, lighting, and equipment), geometry and orientation of the building, insulation of the envelope, tightness of the building (infiltration), etc. (Henson & Lamberts 2011)

New and retrofitted buildings are the subject of many research studies evaluating the impact of contributory factors on the considerable gap between their predicted and actual thermal behaviour (Osaji et al. 2013). A question has risen: to what extent the local climates (microclimates), especially in the urban areas, have an impact on the thermal behaviour of a building? This paper addresses the case of microclimate influence on the accuracy of predictions of buildings' thermal performance.

The objectives of this research are:

- Compute energy demands for a variety of buildings of different types and locations using an energy simulation tool.
- Analyze the weather data and compare energy demands of these buildings against each other and against the standardized case.
- Identify tendencies and discrepancies with regard to the accuracy of the thermal predictions and formulate recommendations for possible solutions.

1.2 Motivation

Buildings are responsible for more than 40% of global energy use and one third of global greenhouse gas emissions, both in developed and developing countries (UNEP 2009). The current situation in the European Union is that out of the total energy consumption the households and commercial buildings account for 25% and 15%, respectively. Heating represents 70% of the household energy consumption and is responsible for 14% of greenhouse gas emissions (Market Observatory for Energy 2010).

This suggests that there is a great potential in energy saving by reducing the heating demand which, in return, would also help decrease the current levels of greenhouse gas emissions. This could help countries in the European Union achieve 20% reduction compared to 1990 levels in greenhouse gas emissions and attain 20% increase in energy efficiency by 2020 (European Commissions 2014). Austria, in particular, has as national goal an extra 16% emissions reduction in the same period of time, so any heating demand savings would be of great help in achieving this objective (Austrian Energy Agency 2012).

Urban areas in Europe are very dynamic entities due to the on-going socio-economic, political, and demographic changes; for example, they are becoming more crowded due to migration inflows (European Commission 2011). According to World Health Organisation (2010), 54% of the current world population live in urban areas compared to 34% in 1960 and this is predicted to grow to 70% by 2050. This population evolution leads to an increased demand for new buildings (that are expanding both horizontally and vertically), roads, plants, cars, etc. In other words, the further development of the urban areas is inevitable (European Commission 2011). Consequently, we are witnessing a major change in urban surface radiative and thermal properties. This change is significantly influenced by the geographic location and local weather variations of the urban area and it is considered one of the main causes behind the Urban Heat Island formation. This well-known phenomenon generates an increase not only in energy demand but also in cooling demand and is associated with higher air pollution and greenhouse gas emissions. (EPA 2008)

According to UNEP (2009), the building sector, compared to other important polluting sectors, has the biggest potential for improvement by cutting on related greenhouse gas emissions. The design of energy efficient buildings, especially in urban areas, is one of the main concerns of scientists and professionals all over the world, being considered a priority in the global efforts to reduce climate change (UNEP 2009).

1.3 Background

1.3.1 Overview

In pursuit of energy efficiency in buildings (residential, non-residential), countries around the world, including Austria, have adopted energy standards and guidelines (OIB 2011a). However, despite having energy standards in place, the household sector still suffered a decline in energy efficiency in the last years (Austrian Energy Agency 2015). New buildings have been built and other renovated to follow nowadays energy efficiency standards, but the situation hasn‘t changed much; on the contrary, an increase in energy consumption has been observed. This paradoxical situation has raised the question whether new buildings are as energy efficient as predicted in the design stage or the gains in energy efficiency are surpassed by energy demand increases due to negative climate effects and addition of more and larger dwellings (Austrian Energy Agency 2015).

Santamouris et al. (2001) discussed the influence of higher ambient temperatures on heating and cooling energy demands. For a typical building in the city center of Athens the heating loads were indeed reduced by 30-50% but, in the same time, the cooling loads almost doubled. Following further assessments, researchers concluded that this is due to the reduction of natural ventilation rates inside street canyons, which was calculated to be up to 10 times smaller when compared to the natural ventilation induced by air flows of undisturbed ambient meteorological conditions.

Mahdavi et al. (2008) showed that significant fluctuations in the buildings' predicted heating and cooling energy demand are also due to the use of different weather data. Predictions based on long-term past weather data and those that take climate change projections into account are prone to deviate considerably from each other. Using local meteorological data vs standard weather files for the whole city would also result in different energy demands.

Orehounig et al. (2011) suggested the use of predictions for microclimate changes right from the urban development stage. This would allow comparing alternative building designs that lead to more energy efficient neighborhoods.

Allegrini et al. (2012) used coupled BES - CFD simulations to study the three main aspects of the urban microclimate (in order of importance): (i) the radiation exchange between neighboring buildings, (ii) the UHI effect and (iii) the reduced convective heat transfer due to wind sheltering. In order to use the radiation model from BES (initially developed for interior spaces) to simulate outdoor spaces, the author used modeled street canyons as outside "atria" with an open ceiling. He concluded that the urban microclimate has a strong influence on space cooling and heating energies and it needs to be taken into account when predicting energy demand.

Urano et al. (2014) indicated that the cooling load may be underestimated if we fail to take into consideration the solar reflection of tall buildings from the neighborhood.

Evins et al. (2014) presented a novel approach that allows for the local wind flow information obtained from computational fluid dynamics (CFD) simulations to be used in detailed building simulations. Using a trained statistical emulator, reasonably accurate data is delivered to the energy simulation at a very low computational cost (and time). The author proves that the use of local wind speed values has a moderate impact on energy demand, but there is a shift from cooling to heating that might influence the passive designs (natural ventilation).

1.3.2 Microclimate and urban area

The particular climate associated with a small-scale region, garden, park or a city neighbourhood is defined as microclimate (MetOffice 2016). Simultaneous comparison of meteorological parameters from weather data (air temperature, relative humidity, wind speed and direction, solar radiation precipitation) amongst numerous locations in an urban area indicates the existence of different microclimates within that area (Kiesel et al. 2012). These microclimates are influenced by both natural and human factors including: vegetative cover, soil type, topography, anthropogenic heat releases from energy consumption (cars, air conditioners), built structures, and industry (Mahdavi 2014). Assessing the negative impact of some of these factors (e.g. built area fraction, urban canyon aspect ratio, and surface albedo) on microclimate, Mahdavi et al. (2013) and Kiesel et al. (2013b) defined a set of variables for mitigation and adaptation purposes by addressing the main three domains: building, pavements and vegetation. The expected benefits of such measures were then evaluated using computational tools (computational fluid dynamics). Different scenarios were simulated and strong influences on the local climate conditions were observed.

This showed that microclimate variance is present in urban areas with huge repercussions for the energy budget of the city (Mahdavi 2014) and, consequently, on thermal performance of buildings.

Figure 1 clearly reveals the effect of human factors on the average surface temperature throughout the 20th century (IPCC 2007).

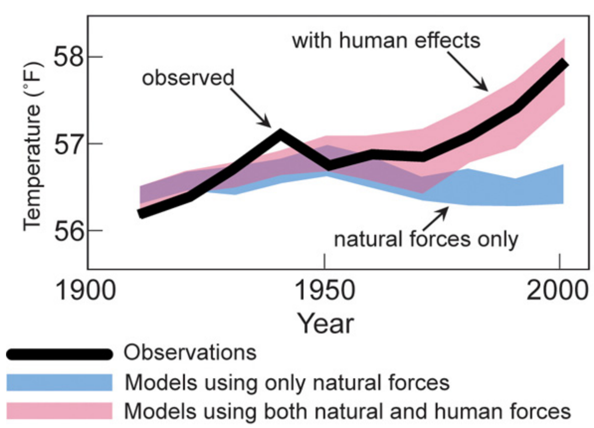

Figure 1 Observed changes in surface temperature versus models using only natural, and natural and anthropogenic forces during the 20th century (IPCC 2007)

The project "Urban fabric types and microclimate response - assessment and design improvement" (Stiles et al. 2014) evaluated the impact of a small scale structure of the urban fabric on the heat island effect and other urban climate phenomena, with the intent to ameliorate the local climate conditions. Nine different urban fabrics types, illustrated in Figure 2, each split in three sub-types, were created considering the local climate, topography, open space patterns, and buildings.

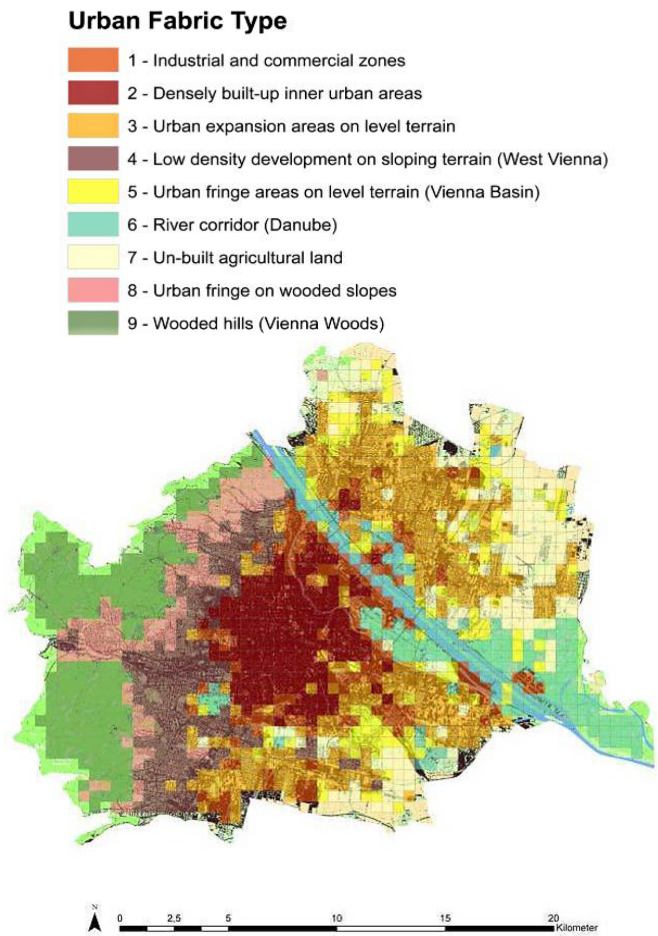

Figure 2 Urban fabric types (Stiles et al. 2014)

One of the conclusions drawn from the study is that cities tend to overheat during the hot summer and they become very sensitive to any change in climate. Results also showed that there is a close interaction between the open space structures and local climate and that microclimate conditions are highly fluctuating from one urban fabric type to another. A grid of 500x500m quadrants allows for different microclimates to be spotted in the same urban fabric type. The different types and densities of built structures as well as different percentages of paved surfaces have a significant impact on heat storage capacities, shading conditions, and air ventilation. Microclimate simulations showed that the cooling effects of urban green areas depend on the distribution of the trees and the width and orientation of the open space. A microclimate, through its weather files, defines the exterior conditions that are fundamental to assessing energy performance in buildings. Therefore, the design of future energy efficient buildings is subject to microclimate assumptions. (Stiles et al. 2014)

1.3.3 Building energy simulation and uncertainties

Energy simulation models are used to calculate energy demands for new and retrofitted buildings as well as to analyze the thermal comfort of their occupants. They are mainly used to compare architectural design alternatives (Maile et al. 2007). Thermal simulation models calculate the heat transfer between a building's exterior and interior environments. The possible heat exchange processes between a building and its exterior environment are illustrated in Figure 3.

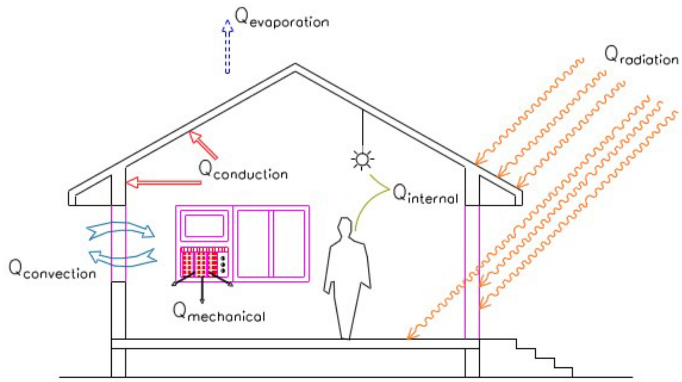

Figure 3 Heat exchange processes between a building and exterior (MNRE 2010)

Conduction through envelope, internal convection and radiation, radiation through windows and building envelope, heat storage, convective heat transfer through ventilation and internal heat gains (people, lighting, equipment and HVAC systems) are some examples of heat exchange processes. The required input data for energy simulations is depicted in Figure 4 and consists in data concerning: the building' characteristics (e.g. construction, geometry, orientation), material properties (e.g.: density, emissivity, thermal conductivity), weather (e.g.: solar radiation, wind speed, humidity), operating strategies and schedules, and internal loads (e.g. internal gains, air exchange rates and infiltrations). (MNRE 2010)

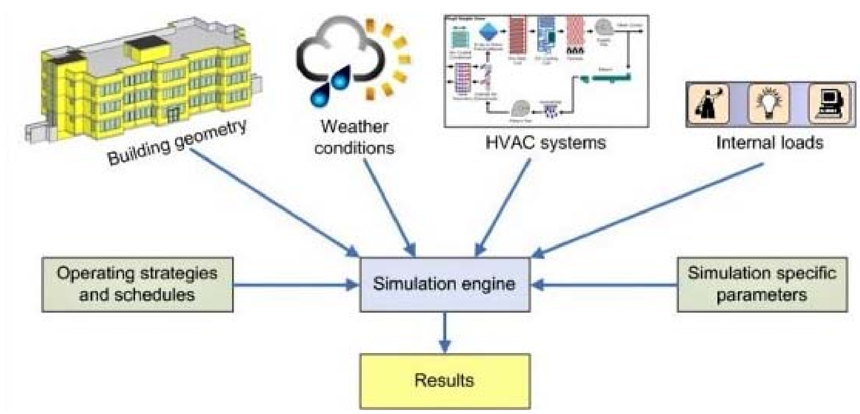

Figure 4 Input data for detailed building performance simulation (Maile and al. 2007)

Internal and external loads should provide complete information for an energy balance within a space. The more detailed the simulation tools are, the better the simulation performance is according to Yezioro and al. (2008). Despite all efforts, uncertainties will still exist and they have an important impact on simulation results. Uncertainties are grouped in 3 categories: environmental, workmanship and quality of building elements, and behavioral (Ramallo-González 2013). Only the first uncertainty is treated here. One of the biggest challenges for design comparison is the quality of weather data. Environmental uncertainties are due to the climate change and synthetic weather data. Given the fact that buildings have a long life span, they will most likely operate in future altered climates (caused by, for e.g. global warming); the influence of the microclimate on predicted thermal behavior of buildings being the subject of the current thesis.

1.3.4 Energy efficiency in buildings

Nowadays, the focus is on reducing energy demand (e.g.Henson & Lamberts 2011). Efficient energy use or using less energy but still providing the same service matches some of the definitions of energy efficiency (IEA 2013). Energy efficiency in buildings became an ardent subject during the energy crisis in 1970 (JCER 2012). Therefore, building standards and guidelines are established everywhere in the world and energy performance certificates are required for each type of building. In Austria, the Austrian Institute of Building Technology (OIB 2011a) through OIB-RL 6 (The guideline no. 6 of the Austrian Institute for Civil Engineering) provides guidelines towards an efficient design for new and retrofitted buildings (residential and non-residential), presenting minimum requirements regarding heating energy demand and thermal behavior of the building envelope. Figure 5 shows the heating energy demand brackets and their corresponding ratings.

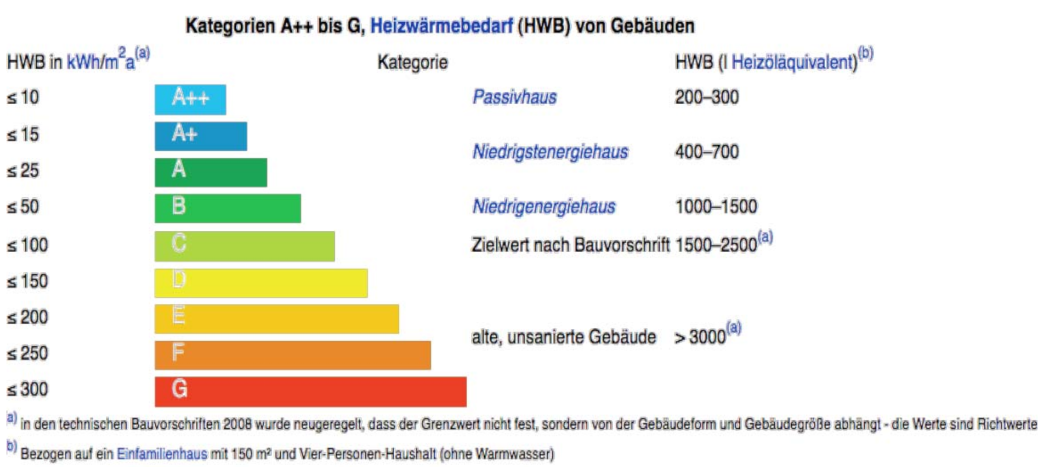

Figure 5 Energy efficiency ratings Austria excerpt from OIB-RL 6 (2011a)

The calculation methodology behind energy performance certificates is the quasi-steady-state method. According to it, the heat balance of a building is calculated on a monthly basis using adjusting utilization factors to account for dynamic effects. Conventional input data includes building geometry, thermal properties of different building elements (U-Values), transmission, ventilation, and infiltration losses, as well as internal and solar gains. A reference climate of 3400 heating degree days is used to calculate monthly climate data. Furthermore, this could be adjusted to account for different locations based on region and altitude. (European Commission 2010)

A more thorough way to assess the thermal performance of a building is the dynamic method. This method evaluates the thermal behaviour of a building over small periods of time (usually hourly steps) over 365 days. The aforementioned input data is modeled in each building zone. Building energy simulation (BES) software use dynamic thermal simulations to resolve the thermal heat balance of a building. (European Commission 2010)

Examples of energy guidelines from OIB-RL6 (2011a) are: the low energy house standard (heating demand between 25 kWh/m^2a and 50 kWh/m^2a) and the passive house standard (15 kWh/m^2a). The parameters looked upon when talking about energy efficiency are: the building envelope (influence on thermal performance of the building and the comfort of the interior environment), the climate conditions at the building site (influence on heat gains, ventilation), the tightness of the building envelope (influence on leaks, infiltration), and proper shading and glazing. When talking about low energy and passive house constructions, the tightness of the building is important for achieving thermal specifications (OECD/IEA 2013). According to AEA (2012), 38% of the final energy consumption is used for heating, this amount being divided between: residential sector (56%), commercial and public services (39%), industry (4%) and agriculture (1%). Looking at the figures above, there is a huge potential for energy savings and CO2 reduction in residential and non-residential sectors via refurbishments and building of new energy efficient constructions. Energy efficient buildings translate in less energy consumption and reduced environmental impact. According to Santamouris (2001), reducing energy demand of buildings in urban areas is still possible, leading to a more sustainable use of energy resources. EPBD (Energy Performance of Building Directive) states that beginning with 2020 all new buildings should follow the standards for low energy buildings, otherwise called “Nearly Zero Energy building” (European Parliament 2010).

1.4 Research questions

Mahdavi et al. (2014) consider cities, like Vienna, to display strong microclimate variations from one location to another within the city. The current research intends to focus on the importance of microclimate assumptions on the prediction of thermal behavior of buildings. For this purpose, the approach adopted is described below:

- Three buildings of different functions, sizes and constructions have been chosen.
- Weather files for five consecutive years and three different locations (8km maximum distance in between the stations) within Vienna, Austria, representing different microclimates (city center and urban peripheral) were obtained from meteorological stations close by. Additionally, one standard weather file usually employed in simulation for Vienna was used.
- Building energy simulation for selected models is performed using local microclimate boundary conditions (represented by the 15 weather files plus a standard weather file as mentioned above). User profile assumptions in accordance with ÖNORM B8110-5 (2011) and construction materials following the minimum requirements stipulated in OIB-RL 6 (2011a) were used.

The aim is to answer the following questions:

1. How does the buildings' thermal performance vary over a 5-year period of time in the city of Vienna, on an annual basis, when local weather files are employed in simulations? How does it deviate, on a monthly and annual basis, from the case when a reference weather file is used in simulations? Are these deviations significant and following a certain trend?

Results of the building energy simulations, illustrated through graphs and tables will be explored and interpreted according to our initial and assumed conditions. Annual and monthly variances of the thermal performance on temporal and spatial scales will be evaluated and later on compared against the standard case.

2. How does the buildings' thermal performance vary depending on the location?

To answer this question analysis of weather factors and parameters will be performed. Annual and monthly variations of thermal performance will be visually compared across different locations and linked to the microclimate variance noted from weather analysis.

3. How does the buildings' thermal performance vary depending on the type of building?
Same building thermal performances will be compared at each location, over the studied period of time.

2 METHOD

2.1 Overview

Thermal performance for three types of buildings will be simulated for the 2008 – 2012 period using local weather files from three locations in Vienna as well as a standard weather file. Throughout this research, the microclimate (represented by weather data) is treated as independent variable and the energy demand of the building as dependent. Internal conditions (due to occupancy, equipment, and lighting), buildings' materials and geometry are considered controlled variables (that remain constant during simulation and analysis).

Many Building Energy Simulation tools are available today and are used for the evaluation of the thermal performance in buildings (compliance with the standards for new and retrofitted buildings, benchmarking and policy making, comparing designs) (Henson & Lamberts 2011). For this research, EDSL 9.3.1 TAS has been used (EDSL 2007a).

Weather stations monitoring the atmospheric conditions are not available for each building site. Therefore, simulated weather data (ex: test meteorological years) that are downscaled and processed using Meteonorm (Meteotest 2007) are used instead. For this study, the simulations are done using empirical weather data obtained from local meteorological stations, shown in Figure 6, that are close to the building site. For comparison purposes, a weather file, International Weather for Energy Calculations (IWEC), developed specifically for the city of Vienna (Schwechat) illustrated in Figure 6, will be used (ASHRAE 2001).

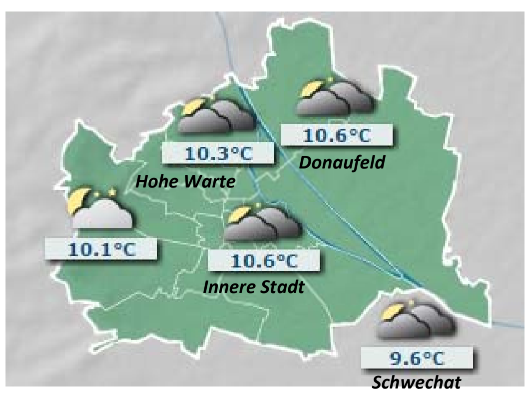

Figure 6 Position of weather stations in Vienna (ZAMG 2015)

2.2 Building energy simulation

EDSL TAS Engineering is a building modelling and simulation tool capable of performing dynamic thermal simulations in order to compute energy consumption, CO_2 emissions, operating costs and occupant comfort. TAS version 9.3.1 is employed in the current study. This research is concerned only with the first TAS task mentioned above. TAS uses 3D conduction, convection and radiation calculations simulating how a building interacts dynamically with its external environment, using hourly weather data to calculate not only peak loads, energy demands, sensible and latent loads, but also condensation risks, mean radiant temperatures, resultant temperatures, surface temperatures, dry bulb temperatures etc. (EDSL 2007b). Figure 7 illustrates TAS schematic representation of heat transfer mechanism in buildings.

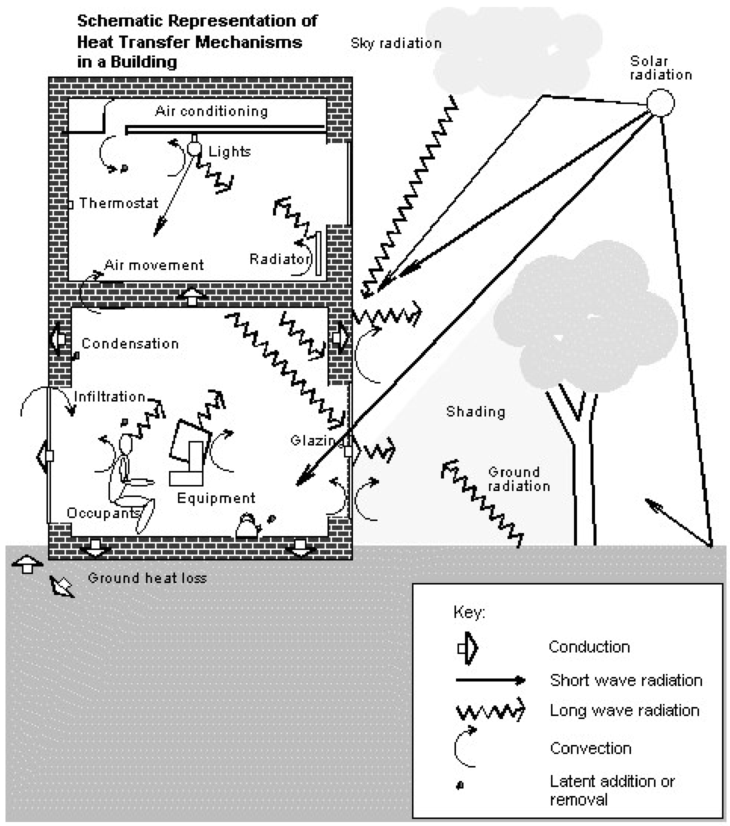

Figure 7 Heat transfer process in TAS (EDSL 2007b)

Conduction through the fabric of the building is interpreted in a dynamic way using the "The Thermal Response factor technique" (Stephenson and Mitalas 1967), which expresses the conductive heat flow at the surfaces of any building element as a function of the temperature history of these surfaces. A maximum of 12 layers can be treated. (EDSL 2007a)

Convection (internal and external) at building surfaces is expressed, through empirical and theoretical relationships, as a function of the temperature difference, surface orientation and wind speed (in case of external convection). (EDSL 2007a)

Long-wave radiation exchange is calculated with Stephan-Boltzman law (EDSL 2007b) using surface emissivity (of the surface layer) input from thermophysical properties of materials stored in the database. Long-wave radiation from the sky and the ground is evaluated using empirical relationships. (EDSL 2007a)

Solar radiation (absorption, transmittance and reflection) of each element is calculated from the solar data in weather file combined with the thermophysical properties of the building elements. First splitting it into direct and diffuse components and then using the knowledge of sun position and empirical models of sky radiation, the incident fluxes are calculated. (EDSL 2007a)

Internal conditions (internal gains from light, occupants and equipment, infiltration and ventilation rates as well as plant operation specifications and schedules) are specified for each zone and grouped in profiles that define that zone. (EDSL 2007a)

Gains are split into radiant (distributed among the zone surfaces) and convective (distributed into the air) portions. (EDSL 2007a)

The sensible heat balance for a zone takes in consideration the individual energy balances for the air and each of the surrounding surfaces throughout representative equations. Furthermore, equations describing energy balances at the external surfaces are combined with the equations above and solved simultaneously to generate air and surface temperatures plus zone loads, for every hour of the simulation (EDSL 2007a). TAS has a modular design, consisting of three main programs: 3D Modeller, Building Simulator and Results Viewer. Figure 8 represents the logical schema of workflow in TAS.

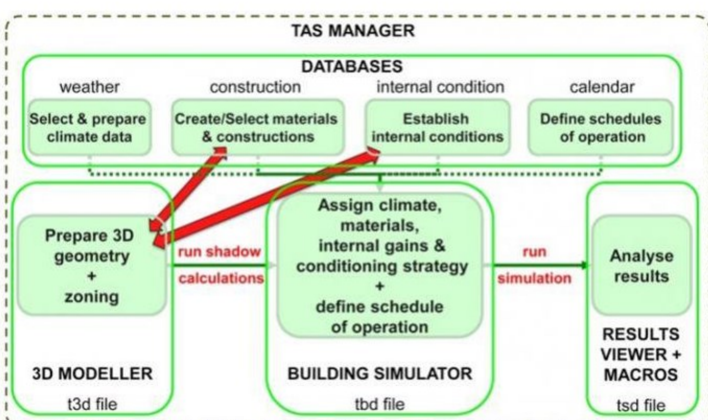

Figure 8 Schema of the Workflow in TAS (AA Environment and Energy Programme 2010)

A general (simplified) heat balance equation utilised to obtain the heating/ cooling loads using hourly interactions and taking into account the daily fluctuations of the climate conditions is presented in the formula 1 below and illustrated in Figure 9. (Universite de Geneve 2005)

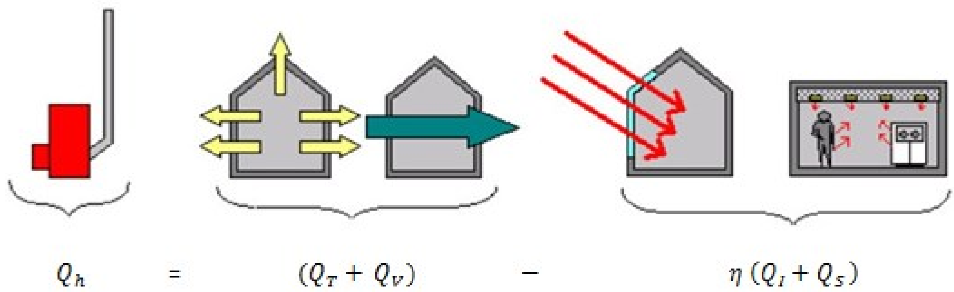

Figure 9 Energy Management in buildings (Universite de Geneve 2005)

$$Q_h = (Q_T + Q_V) - \eta\,(Q_I + Q_S) \qquad (1)$$

Where:

Q_h *Heating/cooling demand*

Q_T *Heat transfer via transmission*

Q_V *Heat transfer via ventilation*

Q_i *Internal gains*

Q_s *Solar gains*

η *Efficiency of gains (as a function of thermal mass)*

According to Demacsek (1999), considering the thermal mass of building, rough assumptions about gains' efficiency are made, illustrated in Table 2-1:

Table 2-1 Efficiency of gains

Construction Type	η
Massive	1
Medium	0.98
Light	0.9

2.3 Standards and Guidelines

As of May 2008 in Austria, Energy Performance Certificates are required to accompany any sale, rent or lease of buildings, independent of the year of construction (Lyons and IEEP 2013) (Austrian Energy Agency 2015). There are 9 provinces in Austria, each with its own regulations regarding building codes and air pollution control. The Austrian Institute of Construction Engineering (OIB) implemented the Guideline 6 (OIB-RL6) for the harmonization of the 9 building codes of the OIB-RL6 provides the basis for the design of thermal envelopes, internal conditions and cooling and/or heating systems (Austrian Energy Agency 2013).

Both residential and commercial buildings are the subject of the present research. In accordance with ÖNORM B 8110-5 (2011), an excerpt of “Thermal insulation in building construction, Part 5: Model of climate and user profiles” is presented in Table 2-2 that also shows the values used in simulations.

Table 2-2 User profile assumptions according (ÖNORM B 8110-5 2011)

Building Type	**Residential**	**Commercial**
Heating set-point temperature [°C]	20	20
Cooling set-point temperature [°C]	27	26
Heating system operation (hours)	24	14
Cooling system operation (hours)	24	12
Air exchange rate [h^{-1}]	0.4	1.2
Internal gains (people, lights, equipment) [$W.m^{-2}$]	3.75	3.75
Operation days	365	269

For climate data components, means of calculation are provided throughout ÖNORM B 8110-5 (2011) for: average monthly temperature, monthly sum of global radiation, HDD and CDH. Brief description of these parameters will be presented in chapter 2.4.4. Detailed construction material characteristics used for the current researched models are presented throughout the chapter 2.5 and they have been chosen according to Baubook, which is a product declaration database for implementation of ecologically valuable buildings (BAUBOOK, 2012). An excerpt of the table showing maximum U-values for building components of the thermal envelope are presented in Table 2-3 (OIB 2011a).

Table 2-3 Maximum U-values for building components for new and renovated buildings

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

According to OIB-RL6 (OIB 2011a), maximum heating and cooling energy demands are herein stipulated, as a function of the building usage and geometry (characteristic length) and based on the reference climate. For new residential buildings, heating energy demand is calculate using formula 2 and for new non-residential buildings formula 3 is being used. Maximum values allowed are specified as well in the corresponding formulas below:

$$HWB_{BGF,WG,max,RK} = 16 \cdot (1+3{,}0/l_c)\ [kWh/m^2a] \qquad < 54{,}4\ [kWh/m^2a] \qquad (2)$$

$$HWB^*_{V,NWG,max,RK} = 5{,}5 \cdot (1+3{,}0/l_c)\ [kWh/m^3a] \qquad < 18{,}7\ [kWh/m^3a] \qquad (3)$$

Where:

$HWB_{BGF,WG,max,RK}$ *Specific heating demand for new residential buildings, gross floor area related [kWh/m²a]*

$HWB^*_{V,NWG,max,RK}$ *Specific heating demand for non-residential buildings, gross volume related [kWh/m³a]*

l_c *Characteristics length [1/m]*

Cooling demand requirements are also part of the Guideline 6 with only one limit imposed for non-residential buildings equal to 1 $kWh \cdot m^{-3}a^{-1}$ (OIB 2011a).

2.4 Climate data and site details

2.4.1 Overview

Description of climate data, through weather files, is an important part of the definition of the boundary conditions for building energy simulations (Henson & Lamberts 2011).

A wide range of weather data from locally recorded to “typical” year can be employed for simulation purposes. When using energy simulation programs, single year type weather data (e.g. Test Reference Year) should be avoided (as no one year could be representative for a full variability of a long-term record) and instead used synthetic weather data, based on improved solar models and averaged long-term climate conditions. As an example of this type of weather files one should mention here Typical Meteorological Year 2 (TMY2), Weather Year for Energy Calculation 2 WYEC2, and International weather for energy calculations (IWEC). (EnergyPlus 2015)

Some of the simulation software provide as an integral part weather and climate data (EnergyPlus 2015). These data are not reliable as they do not describe the actual climate in a certain part of the city and they are typically based long ago measurements. Weather data provided by a climate database and weather generator (based on more recent years), Meteonorm (Meteotest 2007) and by private or public meteorological weather stations may be more reliable alternatives when performing energy simulations. (Mahdavi et al. 2008)

In Austria, Central Institute for Meteorology and Geodynamics operates a network of more than 250 meteorological stations, situated in all climate regions and altitudes, illustrated in Figure 10 (ZAMG 2014). Three locations in the city of Vienna were chosen for this study: Hohe Warte, Donaufeld and Innere Stadt, each served by a meteorological station.

Figure 10 ZAMG network of meteorological stations across Austria (ZAMG 2014)

2.4.2 TAWES - Semi-automatic weather stations across Vienna, Austria

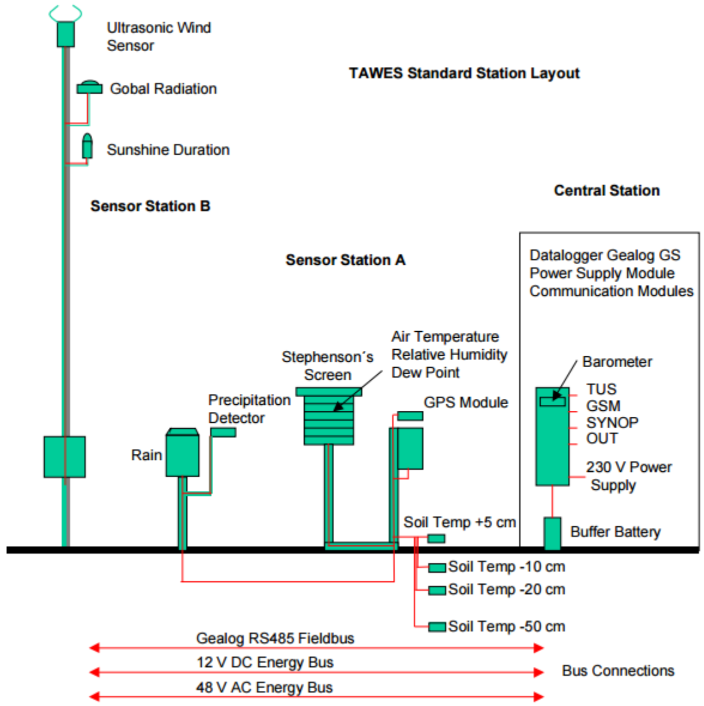

Figure 11 TAWES general standard layout (Penvy & Mair 2008)

TAWES (Figure 11) is used to record data at locations mentioned above. TAWES station has three components: the central station and two sensor stations. Data is transferred through Fieldbus connection from sensor to central station every 10 minutes. Some TAWES stations are equipped with short distance radio enabling wireless data transfer between sensor stations and central station. (Penvy and Mair 2008)

For energy simulations the following elements are required: global radiation, outside air temperature and humidity, wind direction and speed, and cloud cover. Although, the weather stations used in this study were able to provide all input parameters required for thermal simulation, some supplementary parameters were required (Meteotest 2007). Adjustments and data processing was necessary. The conversion from meteorological weather file to .epw (EnergyPlus 2012) file is required, for input in TAS. First, data from the meteorological stations is used as input data in Meteonorm (Meteotest 2007), in order to calculate the solar radiation on arbitrary oriented surfaces at chosen locations. The chosen output file from Meteonorm is an .epw file that hasn't the real wind speed and direction. For editing purposes, EP-Launch Weather converter (EnergyPlus 2012) will be used; wind direction and speed will be replaced with the ones from the meteorological stations (.csv file is obtained). Finally, using EP-Launch converter again, this file containing the real wind data is changed to the .epw file necessary to input in TAS.

2.4.3 Weather station locations and characteristics

The current research concentrates on three microclimates in the vicinity of the following whether stations in Vienna: Donaufeld, Hohe Warte and Innere Stadt, and one reference rural area at Schwechat (airport). Different topographies, morphologies, semantic properties of urban surfaces differentiate them according to Vuckovic (2016). In the Figure 12, the location of these weather stations is indicated on the map of the city of Vienna and their geographical characteristics presented in Table 2-4. Some general characteristics of the weather stations surroundings are also presented below (Stiles et al. 2014).

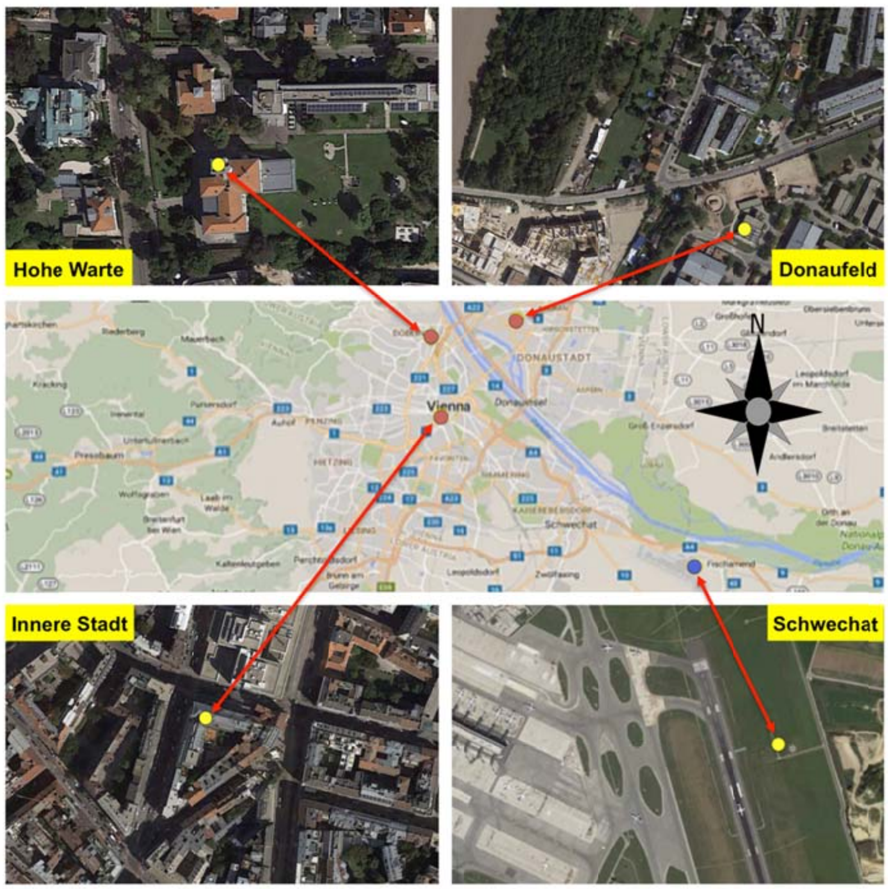

Figure 12 Weather stations location throughout Vienna (ZAMG 2014)

Table 2-4 Meteorological stations as per Stationsliste (ZAMG 2013)

	Hohe Warte (urban peripheral)	Donaufeld (suburban)	Innere Stadt (urban central)	Schwechat (Rural)
Longitude	**16° 21' 21" E**	**16° 25' 53" E**	**16° 21' 59" E**	**16° 34' 11" E**
Latitude	**48° 14' 55" N**	**48° 15' 26" N**	**48° 11' 54" N**	**48° 06' 37" N**
Altitude	**198m**	**160m**	**177m**	**183m**
Height of the anemometer	**209m**	**163m**	**177m**	**183m**

Vienna Hohe Warte (Urban peripheral) - Hohe Warte (HW) station is situated in the North part of the city, region characterized as a low-density residential area situated on a sloping terrain. The local climate is cool and more humid due to proximity to Vienna woods. Detached housing and villas with big private gardens estates and perimeter block developments with inner courtyards heavily vegetated are the representative developments for this area. Vegetation wise, this area is characterized by high quantities of shrub and big tree populations.

Vienna Donaufeld (Suburban) - Donaufeld (D) station is situated in the East part of the city, region characterized as an urban fringe area on a level terrain (Vienna Basin). Hot summer days and cool nights are the highlights of the local climate. This is a low-density suburban area with no tall buildings. Low vegetation and few trees create the landscape of this region.

Vienna Innere Stadt (Urban central) - Innere Stadt (IS) station is situated at the outside limit of the city center towards south, on top of a tall building close to the main library of Technical University of Vienna. This region is characterized as a densely build-up inner urban area. Local climate is described as very hot during the night and warm during winter time. High percentage of seal surfaces and less vegetation area overall are illustrative for this area. Tall, historic and perimeter block developments are considered representative for this region.

Weather station Schwechat (rural, airport) - For this study, an IWEC data file for the city of Vienna is used as the standard weather file, derived from long-term hourly weather data improved with other important parameters for simulation purposes as solar radiation (approximated from sun path diagram) and cloud cover (Energy Plus 2015). Vienna Schwechat 110360 (IWEC) is the weather file name, where Schwechat is a rural area outside of Vienna (airport) and 11036 is the WMO ID assigned to this weather station (WMO 2016).

2.4.4 Microclimate indicators

According to OENORM 8110-2 (2003), for different locations in Austria we can calculate the mean monthly outside temperature, as per formula 4, required to find climate indicators.

$$\theta = a + b\,H \qquad (4)$$

Where:

ϑ	*Mean monthly temperature in [°C]*
H	*See level every 100 m*
a, b	*Coefficient of linear regression*

Table 2 of the same standard presents linear regression coefficients, a and b, derived from records of air temperature of the years 1961-1990 for seven regions in Austria and for each month. The Austrian Institute for Building Technology, OIB, has developed an Excel spreadsheet to create energy performance certificates calculating the energy demands by specifying the building geometry, construction materials and location. From the same excel spreadsheet one can obtain climate indicators specific to a location (OIB 2011). Two climate indicators are of great help when evaluating thermal energy demands in buildings: heating degree days ($HDD_{12/20}$) and cooling degree hours (CDH_{26}). Heating Degree Days express the severity of a certain climate of an area in a specific time period taking into consideration outdoor temperature and room temperature, calculated as per formula 5 below, in accordance with ÖNORM 8110-5 (2011).

$$\begin{aligned} HDD_{20/12} &= \sum \left(\theta_{i,h} - \theta_{e,i}\right) d_i && \text{for } \theta_{e,i} <= 12\ °C \\ HDD_{20/12} &= 0 && \text{for } \theta_{e,i} > 12\ °C \end{aligned} \qquad (5)$$

Where:

$HDD_{20/12}$	*Heating degree days [kd/a]*
$\theta_{i,h}$	*Design minimum comfort indoor temperature [°C],* *Table 2/ Chapter 2.3 Standard and Guidelines* *(in this study 20°C)*
$\theta_{e,i}$	*Mean daily outdoor temperature [°C]*
d_i	*Day of the month when $\theta e,i < 12$ °C, in d*

Cooling degree hours are defined as the sum of the hours when the outside temperature is over the design maximum comfort indoor temperature, in this study, 26°C.

$$CDH_{26} = \sum \left(\theta_{e,i} - \theta_{i,h}\right) h_i \qquad for\ \theta_{e,i} >= 26\ °C$$
$$CDH_{26} = 0 \qquad for\ \theta_{e,i} < 26\ °C \qquad (6)$$

Where:

CDH26 *Cooling degree hours [kd/a]*

$\theta_{i,h}$ *Design maximum comfort indoor temperature [°C],*

Table 2/ Chapter 2.3 Standard and Guidelines

(in this study 26°C)

$\theta_{e,i}$ *Outdoor temperature [°C]*

h_i *Hours when* $\theta e,i > 26$ *°C, in h*

2.5 Building typology and research models

2.5.1 Overview

There are two building categories described in OIB-RL6, chapter 3.1 (OIB 2011a); residential and non-residential buildings, based on predominant usage and size.

a) Residential buildings: single-family house, multi-family houses and apartment blocks. The construction periods, according to Statistics Austria" Census 2011 Gebäude- und Wohnungszählung (2013)" are classified in seven subcategories starting with before 1918. Single-family houses are residential buildings with one to two dwellings. According to Statistics Austria, the multi-family house is defined by two-to four-level residential buildings with about three to ten residential units. The apartment blocks are large multi-family houses and multi-storey residential buildings with more than eleven living units, which are mostly located in larger towns.

b) Non-residential buildings: office building, hotel, hospital and nursing home, school, event centres, home trades, parking garages (Bauer & al. 2013).

In Vienna, due to the increase in demography, 95000 units will be built from 2011 until 2025 (Hartman et al. 2014), meaning 8000 new built dwellings per year (including the new buildings replacing the unsafe demolished ones).

Following the decisions of the European Councils of March and June 2010, Austrian CO2-emission reduction and energy efficiency targets by 2020 should reach the values presented in Table 2-5 (Federal Chancellery 2004).

Table 2-5 European and Austrian targets for 2020

Headline target	**EU target 2020**	**Austrian target 2020**
Employment rate (20 to 64) in %	75 %	77-78 %
R&D ratio	3 %	3,76 %
CO2-emission reduction targets	-20 % compared to 1990 levels (for further details see "Effort Sharing Decision", 2009/406/8EC)	-16 % for emissions not covered by the ETS (base year: 2005)
Renewable energy	20 %	34 %
Energy efficiency	Increasing energy efficiency towards 20 % (base year 2005)	Stabilization of final energy consumption (base year 2005)

Consequently, the present study is focused on new constructions that are representative for each category presented above (Asamer & al. 2014).

2.5.2 Single Family House (SFH) - Residential building, New, Detached.

Single family houses are mainly constructed in housing developments in peripheral areas of cities (Amtmann 2011) and very rarely close to the city centre. The researched single family house presented in Figure 13 has two floors and no basement.

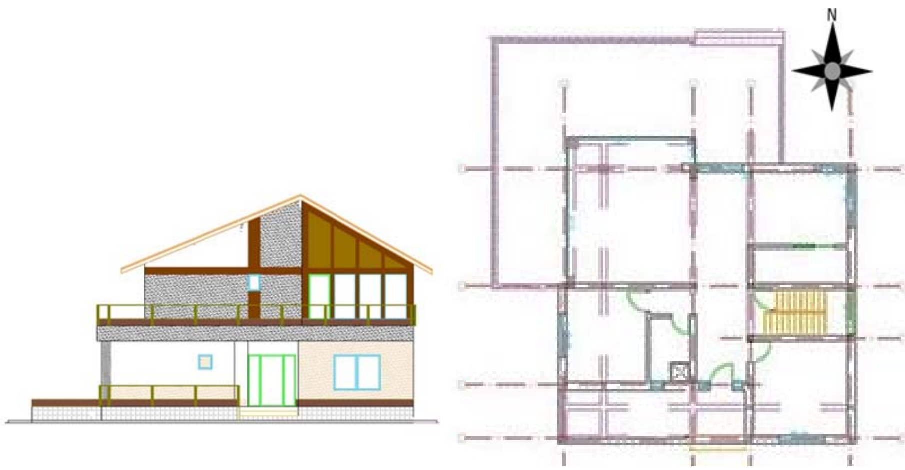

Figure 13 SFH front facade and layout (1cm represents 3m)

The thermal zones created in TAS for the SFH model are illustrated in Figure 14. When splitting a building in thermal zones, the following circumstances should be evaluated:

- Orientation
- Contact with earth, outside air, unheated surface, heated surface
- Connectivity with other rooms
- Internal conditions
- Envelope materials

Figure 14 SFH model zones from TAS Modeller south façade

The single family houses are representative for areas like Hohe Warte and Donaufeld. The envelope of the house is brick wall insulated on the exterior. General information concerning this building is presented in Table 2-6, details about construction materials are resumed in Appendix Table A-1 and the layouts are illustrated in Figures A1 to A3.

Table 2-6 SFH Geometric and thermal characteristics

Building type	SFH
Number of heated floors	2
Gross Floor Area [m^2]	259
Net Floor Area [m^2]	226
Volume [m^3]	798
Envelope Area [m^2]	580
Window Area [m^2]	70
Mean envelope U-Value [Wm^{-2}K^{-1}]	0.48
V/A [m]	1.38

2.5.3 Apartment block (AB) – Residential Building, New, Multi residential

Multifamily houses are typical for Viennese landscape and they accommodate around 87% of Vienna's population (Magistrat der Stadt Wien 2015). Densely built-up areas with narrow or large canyon streets can be found in all the districts in Vienna. Medium weight precast structure with load bearing core and exterior walls, oriented east-west and receiving natural light the whole day are the main characteristics of the chosen model presented in Figure 15 (MA18 2008). Attic balconies offer protection for wind and sun. The thermal zones created in TAS for the AB model are illustrated in Figure 16.

Figure 15 AB north facade and layout (Querkraft Architects 2009) (1cm represents 4m)

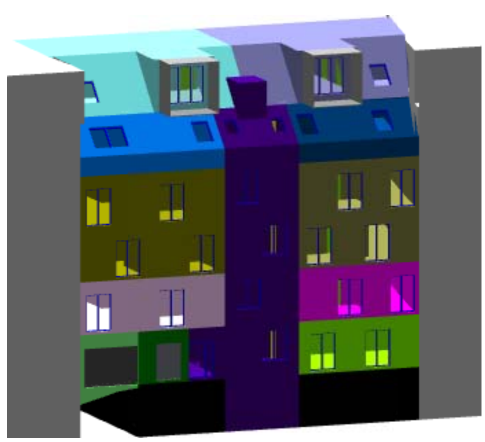

Figure 16 AB model zones from TAS Modeller north façade

General information concerning this building is presented in Table 2-7, details about construction materials are resumed in Appendix Table A-2 and the construction layouts are illustrated in Figures A4 to A7.

Table 2-7 AB Geometric and thermal characteristics

Building type	AB
Number of heated floors	6
Gross Floor Area [m^2]	1385
Net Floor Area [m^2]	1123
Volume [m^3]	3614
Envelope Area [m^2]	1134
Window Area [m^2]	173
Mean envelope U-Value [$Wm^{-2}K^{-1}$]	0.5
V/A [m]	3.18

2.5.4 Office Building – Non-Residential Building, New, Office

In non-residential sector, as specified in the "Europe's building under microscope" (BPIE 2011), office buildings are an important segment. In Vienna, office buildings represent 18% of the non-residential sector according to Statistics Austria (2001). This office building is a medium weight structure with underground garage and 7 floors. Glazed area is distributed mainly on the south façade, less on east and west facades, shown in Figure 17. The thermal zoning from TAS modeller is presented in Figure 18. General information concerning this building is presented in Table 2-8, details about construction materials are resumed in Appendix Table A-3 and the layouts are illustrated in Figures A8 to A11.

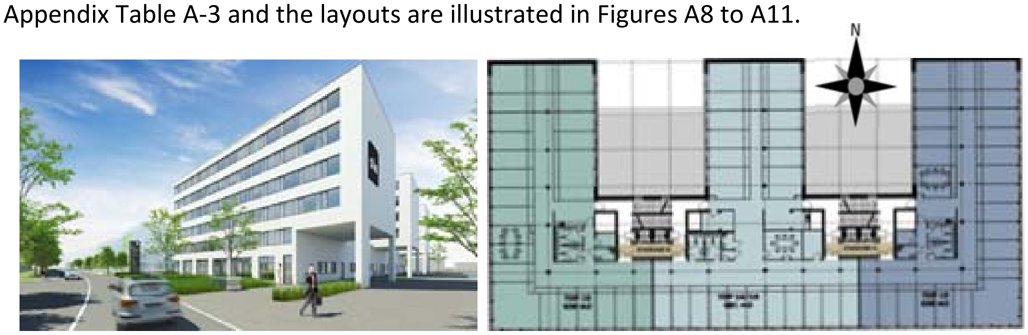

Figure 17 Office perspective and layout (Erste Group 2009)(1cm represents 10m)

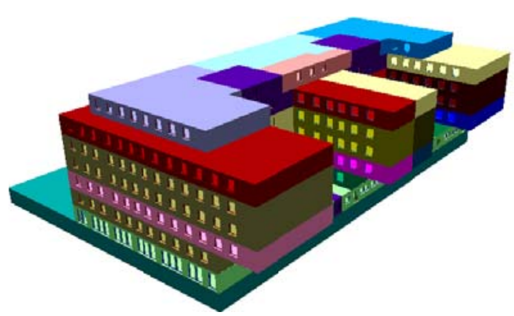

Figure 18 Office model zones from TAS Modeller, north façade

Table 2-8 Office Geometric and thermal characteristics

Building type	Office
Number of heated floors	7
Gross Floor Area [m^2]	15320
Net Floor Area [m^2]	12780
Volume [m^3]	45960
Envelope Area [m^2]	11295
Window Area [m^2]	1212
Mean envelope U-Value [Wm^{-2}K^{-1}]	0.46
V/A [m]	4.07

2.5.5 Building the actual models: geometry, envelope thermal characteristics and boundary conditions

Three building models, described above, were used in thermal energy simulations, virtually positioned at three different locations in the city of Vienna, for 5 consecutive years. Furthermore, building energy simulations were completed for all buildings for a reference weather file usually employed for simulation purposes (EnergyPlus 2015).

The components of thermal building envelope are illustrated in Figure 19 (A-NULL 2012) and their U-Values are presented in Table 2-9 (excerpt from construction elements in APPENDIX A, Tables A-1 to A-3) and they are in accordance with Guideline 6 (OIB 2011a). The construction's building components and building materials were chosen from BauBook (2012), where physical and ecological building guidelines for construction materials used in new and refurbished projects are listed. The technical responsibility for physical building guideline lies with the Vorarlberg Energy Institute (EIV) and for building ecology guideline with IBO (Österreichisches Institut für Bauen und Ökologie) (BAUBOOK 2012).

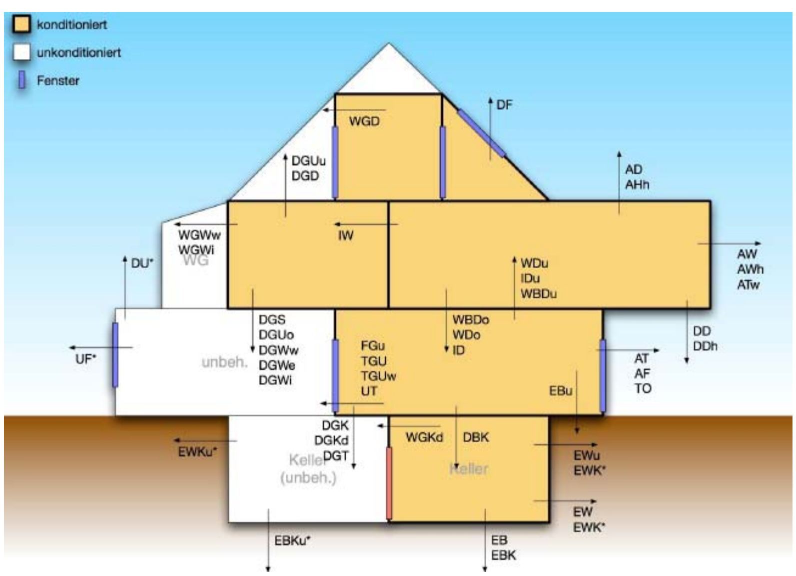

Figure 19 Thermal building components abbreviations according to ArchiPHYSIK 11

Table 2-9 Thermal building envelope components U-Value

Type	External wall	Floor to Unconditioned space	Slab on grade	Slab underground	Slab underground to Unconditioned	Wall to ground	Roof / Flat Roof	Exposed ceiling	Window	Door
	AW	**DGK**	**EBu**	**EB**	**EBKu**	**EW**	**DGUu**	**AD**	**AF**	**AT**
					U-Value [$Wm^{-2}K^{-1}$]					
SFH	**0.3**	**-**	**0.35**	**-**	**-**	**0.3**	**0.17**	**0.2**	**1.4**	**1.7**
AB	**0.35**	**0.3**	**-**	**-**	**0.4**		**0.2**	**-**	**1.4**	**1.7**
Office	**0.35**	**0.3**	**-**	**0.3**	**-**	**0.3**	**0.2**	**0.2**	**1.4**	**1.7**

2.6 Statistical Analysis

In the present study the following statistical analysis will be employed: time series analysis to extract eloquent statistics about the data. For time series analysis will be used relative deviations of the maximum values from the minimum values to determine the magnitude of discrepancies along the studied interval of time, using equation (7) below.

$$RD = \frac{(X_{max} - X_{min})}{X_{min}} \times 100 \ [\%] \qquad (7)$$

Where:

RD *Relative deviation*

X_{max} *Maximum value of the series*

X_{min} *Minimum value of the series*

3 RESULTS AND DISCUSSIONS

In order to interpret the results of the current research, first the microclimate factors (described through the weather data from the meteorological stations) and the microclimate indicators will be analysed for each location over a 5-year period of time and compared to their corresponding values from the standard weather file usually employed in simulations for the city of Vienna.

Next, the results of the current study are presented in the following subchapters attempting to answer the research questions mentioned in chapter 1 and restated below, by evaluating the magnitude of variations in studied buildings' thermal performance over time, from one location to another and for different types of buildings.

3.1 Microclimate factors and indicators (weather analysis)

Microclimate parameters and indicators for 15 different weather files (monitored weather data over a period of 5 years from 3 weather stations in Vienna) are presented in Table 3-1 and illustrated in Figure 20 to Figure 23. The heating degree days (HDD) and cooling degree hours (CDH) describe the specific climate of a certain location considering the building heating and cooling requirements as per ÖNORM B8110-5 (2011). The indoor temperature for heating is set at 20°C when occupied and 12°C when unoccupied. In the same time, a threshold value of 26°C is used for the indoor temperature when cooling. Annotations used in the tables below are described as following:

STD	*Standard weather file*
$\theta_{e,m}$, MRH,	*Mean annual outdoor temperature, mean relative humidity*
WS , GSR	*Wind speed, global solar radiation*
$HDD_{20/12}$	*Heating Degree Days*
CDH_{26}	*Cooling Degree Hours*
D, HW, IS	*Donaufeld, Hohe Warte, Innere Stadt*

Table 3-1 Microclimate factors and indicators - by location

Location	Year	$\theta_{e,m}$ [° C]	MRH [%]	WS [m s^{-1}]	GSR [W m^{-2}]	$HDD_{20/12}$ [Kd]	CDH_{26} [Kh]
Donaufeld	2008	12.0	71	1.94	136	2743	836
	2009	11.6	74	1.97	139	2945	1068
	2010	10.3	74	1.99	131	3304	1247
	2011	11.3	71	1.87	145	3043	1096
	2012	11.5	69	1.95	143	3038	1898
	Max	12	74	1.99	145	3304	1898
	Min	10.3	69	1.87	131	2743	836
	RD	*17%*	*7%*	*6%*	*11%*	*20%*	*127%*
	Mean	**11.34**	**71.8**	**1.94**	**138.8**	**3014.6**	**1229**

Location	Year	$\theta_{e,m}$ [° C]	MRH [%]	WS [m s^{-1}]	GSR [W m^{-2}]	HDD20/12 [Kd]	CDH26 [Kh]
Hohe Warte	2008	11.5	72	3.41	134	2867	541
	2009	11.1	74	3.36	136	3030	564
	2010	10.0	73	3.36	130	3386	851
	2011	11.2	75	3.30	142	3031	773
	2012	11.3	73	3.37	139	3046	1405
	Max	11.5	75	3.41	142	3386	1405
	Min	10	72	3.3	130	2867	541
	RD	*15%*	*4%*	*3%*	*9%*	*18%*	*160%*
	Mean	**11.02**	**73.4**	**3.36**	**136.2**	**3072**	**826.8**
Innere Stadt	2008	12.7	72	3.00	138	2515	885
	2009	12.2	72	2.94	134	2723	971
	2010	11.1	71	3.00	124	3046	1293
	2011	12.7	72	2.89	137	2515	885
	2012	12.7	72	3.03	138	2515	885
	Max	12.7	72	3.03	138	3046	1293
	Min	11.1	71	2.89	124	2515	885
	RD	*14%*	*1%*	*5%*	*11%*	*21%*	*46%*
	Mean	**12.28**	**71.8**	**2.97**	**134.2**	**2662.8**	**983.8**
STD		**11.4**	**72**	**3.10**	**129**	**2933**	**583**

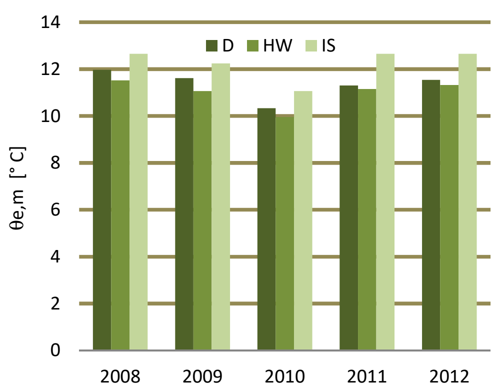

Figure 20 Mean annual temperature

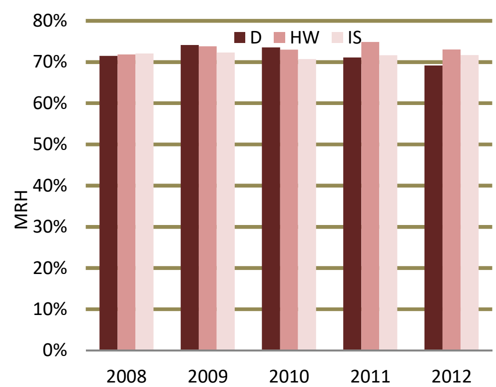

Figure 21 Mean relative humidity

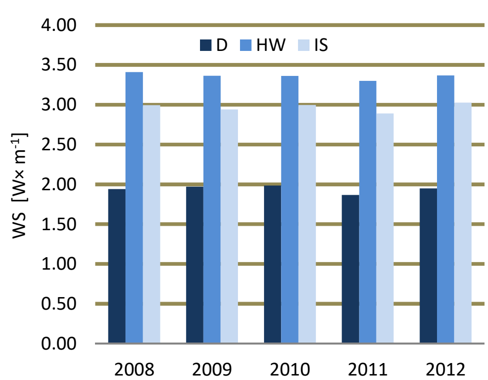

Figure 22 Mean annual wind speed

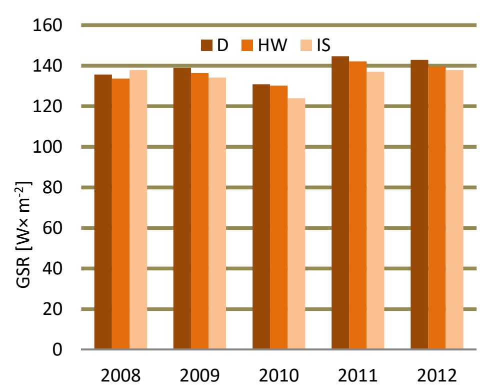

Figure 23 Mean annual global radiation

Table 3-2 Microclimate factors and indicators - by year

Location	Year	$\theta_{e,m}$ [° C]	MRH [%]	WS [m s^{-1}]	GSR [W m^{-2}]	HDD20/12 [Kd]	CDH26 [Kh]
2008	D	12	71	1.94	136	2743	836
	HW	11.5	72	3.41	134	2867	541
	IS	12.7	72	3	138	2515	885
	Max	12.7	72	3.41	138	2867	885
	Min	11.5	71	1.94	134	2515	541
	RD	*10%*	*1%*	*76%*	*3%*	*14%*	*64%*
	Mean	**12.1**	**71.7**	**2.8**	**136.0**	**2708.3**	**754.0**
2009	D	11.6	74	1.97	139	2945	1068
	HW	11.1	74	3.36	136	3030	564
	IS	12.2	72	2.94	134	2723	971
	Max	12.2	74	3.36	139	3030	1068
	Min	11.1	72	1.97	134	2723	564
	RD	*10%*	*3%*	*71%*	*4%*	*11%*	*89%*
	Mean	**11.6**	**73.3**	**2.8**	**136.3**	**2899.3**	**867.7**
2010	D	10.3	74	1.99	131	3304	1247
	HW	10	73	3.36	130	3386	851
	IS	11.1	71	3	124	3046	1293
	Max	11.1	74	3.36	131	3386	1293
	Min	10	71	1.99	124	3046	851
	RD	*11%*	*4%*	*69%*	*6%*	*11%*	*52%*
	Mean	**10.5**	**72.7**	**2.8**	**128.3**	**3245.3**	**1130.3**
2011	D	11.3	71	1.87	145	3043	1096
	HW	11.2	75	3.3	142	3031	773
	IS	12.7	72	2.89	137	2515	885
	Max	12.7	75	3.3	145	3043	1096
	Min	11.2	71	1.87	137	2515	773
	RD	*13%*	*6%*	*76%*	*6%*	*21%*	*42%*
	Mean	**11.7**	**72.7**	**2.7**	**141.3**	**2863.0**	**918.0**
2012	D	11.5	69	1.95	143	3038	1898
	HW	11.3	73	3.37	139	3046	1405
	IS	12.7	72	3.03	138	2515	885
	Max	12.7	73	3.37	143	3046	1898
	Min	11.3	69	1.95	138	2515	885
	RD	*12%*	*6%*	*73%*	*4%*	*21%*	*114%*
	Mean	**11.8**	**71.3**	**2.8**	**140.0**	**2866.3**	**1396.0**
STD		**11.4**	**72**	**3.10**	**129**	**2933**	**583**

Innere Stadt's (IS) constantly higher mean annual temperatures (Figure 20) over the studied period of time, as compared with the other 2 locations, might be influenced by the fact that very compact city centers, crowded areas, and built-up structures that block the heat in (urban heat island effect). Higher altitude, an abundance of tall trees, proximity to Vienna woods for Hohe Warte (HW), and existence of low-height-vegetation and low-rise buildings at Donaufeld (D) could be the reason why these locations record the lowest temperatures.

Mean annual relative humidity (Figure 21) is higher at Hohe Warte and Donaufeld versus Innere Stadt. This might be influenced by the overall greater percentage of vegetative cover and trees and lower percentage of sealed surfaces. In general, however, there are no significant variations from one location to another over the 5-year period of time.

Usually, wind speeds in the cities have reduced intensity compared to an open area (like Schwechat) due to the wind sheltering effect (Allegrini et al. 2012) induced by the surrounding environment (buildings, trees, etc.) According to the stations measurements, the wind speed is constantly and considerably higher at Hohe Warte and Innere Stadt (Figure 22). This phenomenon could be explained by the position of the anemometers at studied locations. According to Table 2-4, the anemometers at Hohe Warte,Innere Stadt, and Schwechat are positioned at similar heights (10m), while at Donaufeld the anemometer is installed at the pedestrian level. This difference in anemometers height could be the reason for recorded lower wind speeds at Donaufeld. Mean annual global solar radiation (Figure 23) does not variate significantly across the analysed locations, but its variation from one year to another is considerable. In Table 3-1 and Table 3-2, it can be noticed significant discrepancies in between the weather files from meteorological stations and the standard file. The mean annual temperature cannot be representative for all the locations in the city, especially not for the Innere Stadt location, where higher temperature values are recorded as noted above. Overall, due to ongoing climate change, the mean annual global solar radiation and the CDH are drastically underestimated in the standard file and this could lead to the underestimation of the cooling loads.

3.2 Temporal results

A strong network of meteorological stations in the city of Vienna helps monitor climate changes over time and forecast their future variations. In this study, energy simulations are performed and buildings' thermal behaviour is calculated using both weather data from the local meteorological stations and one reference weather file, usually employed in energy simulations for the city of Vienna.

The intent is to understand: **how does the buildings' thermal performance vary over a 5-year period of time in the city of Vienna, on an annual basis, when local weather files are employed in simulations? How does it deviate, on a monthly and annual basis, from the case when a reference weather file is used in simulations? Are these deviations significant and following a certain trend?**

3.2.1 Thermal performance variations over a 5-year period

Table 3-3 groups the simulated HED and CED using local weather files and one standard reference file for three locations in Vienna and for three different types of buildings. Figure 24 to Figure 29 illustrate the thermal variations over 5 years and how they compare with the variation of HDD and CDH.

Table 3-3 Heating (HED) and cooling (CED) energy demand for SFH, AB and Office over the years

Year	Location	SFH		AB		Office	
		HED	CED	HED	CED	HED	CED
		$[kWh \cdot m^{-2} \cdot a^{-1}]$					
2008	D	26.7	5.6	12.1	8.2	44.0	13.4
	HW	29.2	4.3	13.6	6.9	51.9	10.8
	IS	24.2	6.7	10.6	9.0	40.9	14.7
	Max	29.2	6.7	13.6	9.0	51.9	14.7
	Min	24.2	4.3	10.6	6.9	40.9	10.8
	RD	*21%*	*56%*	*28%*	*31%*	*27%*	*37%*
	Mean	**26.7**	**5.5**	**12.1**	**8.0**	**45.6**	**13.0**
2009	D	32.1	5.8	17.0	8.8	54.0	14.2
	HW	33.9	4.0	18.3	6.7	56.8	9.6
	IS	30.2	6.5	15.7	9.5	51.3	14.1
	Max	33.9	6.5	18.3	9.5	56.8	14.2
	Min	30.2	4.0	15.7	6.7	51.3	9.6
	RD	*12%*	*62%*	*17%*	*42%*	*11%*	*47%*
	Mean	**32.1**	**5.4**	**17.0**	**8.3**	**54.0**	**12.6**
2010	D	36.8	5.0	19.9	6.8	60.3	11.2
	HW	38.1	3.7	20.5	5.5	62.6	8.6
	IS	34.0	5.7	18.2	7.4	57.1	11.5
	Max	38.1	5.7	20.5	7.4	62.6	11.5
	Min	34.0	3.7	18.2	5.5	57.1	8.6
	RD	*12%*	*52%*	*12%*	*35%*	*10%*	*33%*
	Mean	**36.3**	**4.8**	**19.5**	**6.6**	**60.0**	**10.5**
2011	D	31.7	5.3	15.8	8.3	52.1	14.0
	HW	32.1	4.2	15.9	7.0	52.7	10.9
	IS	28.5	6.5	14.1	9.4	48.2	14.5
	Max	32.1	6.5	15.9	9.4	52.7	14.5
	Min	28.5	4.2	14.1	7.0	48.2	10.9
	RD	*13%*	*53%*	*13%*	*34%*	*9%*	*33%*
	Mean	**30.8**	**5.3**	**15.3**	**8.2**	**51.0**	**13.1**
2012	D	31.2	6.9	15.5	9.4	51.9	17.0
	HW	32.1	5.4	16.1	7.9	53.1	13.7
	IS	28.4	7.6	14.1	10.2	48.4	17.4
	Max	32.1	7.6	16.1	10.2	53.1	17.4
	Min	28.4	5.4	14.1	7.9	48.4	13.7
	RD	*13%*	*42%*	*14%*	*29%*	*10%*	*27%*
	Mean	**30.6**	**6.6**	**15.2**	**9.1**	**51.1**	**16.0**
STD		**29.6**	**5.4**	**15.6**	**7.6**	**52**	**10.8**

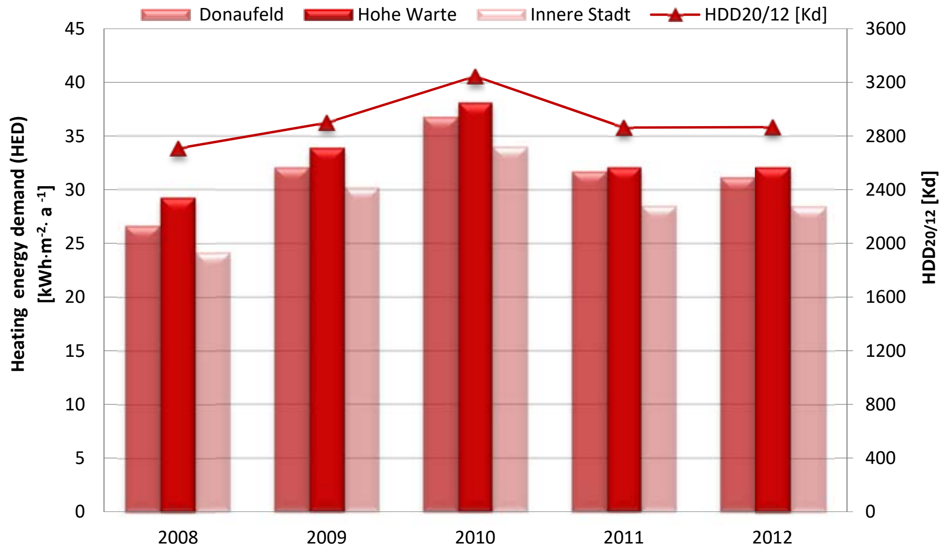

Figure 24 SFH – Variation of heating energy demand over the years

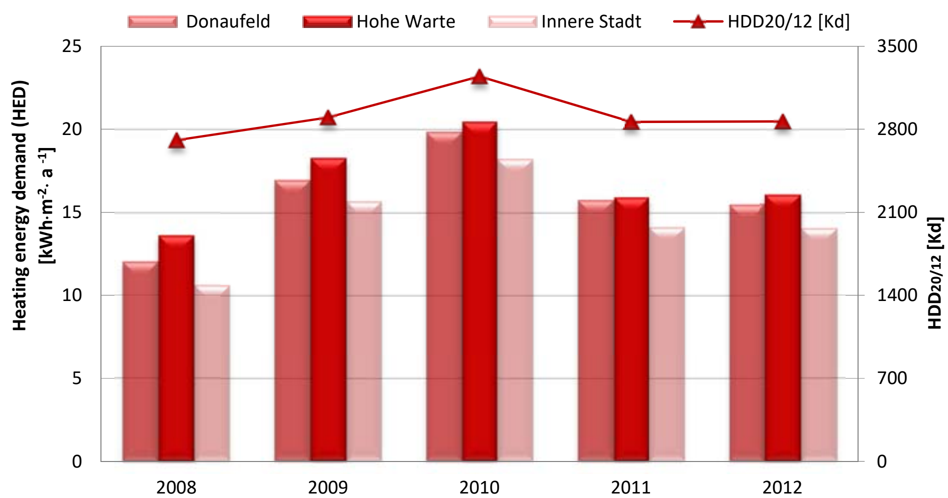

Figure 25 AB – Variation of heating energy demand over the years

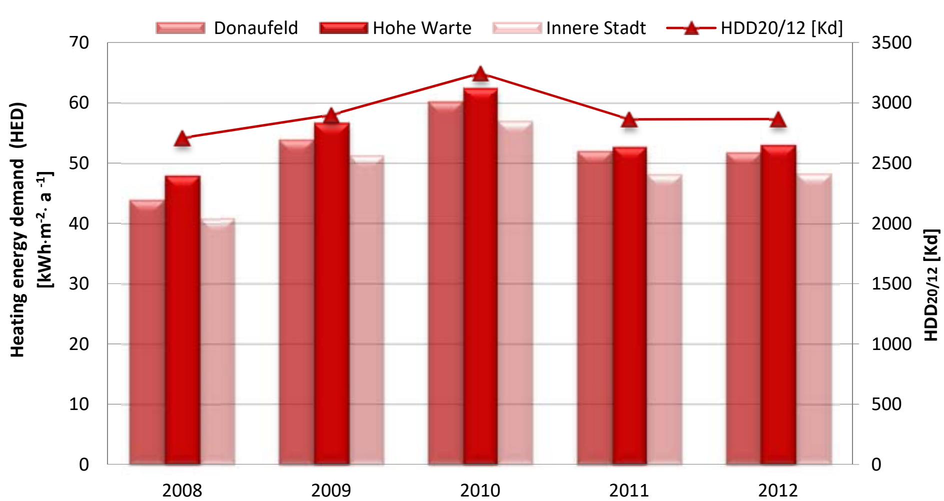

Figure 26 Office – Variation of heating energy demand over the years

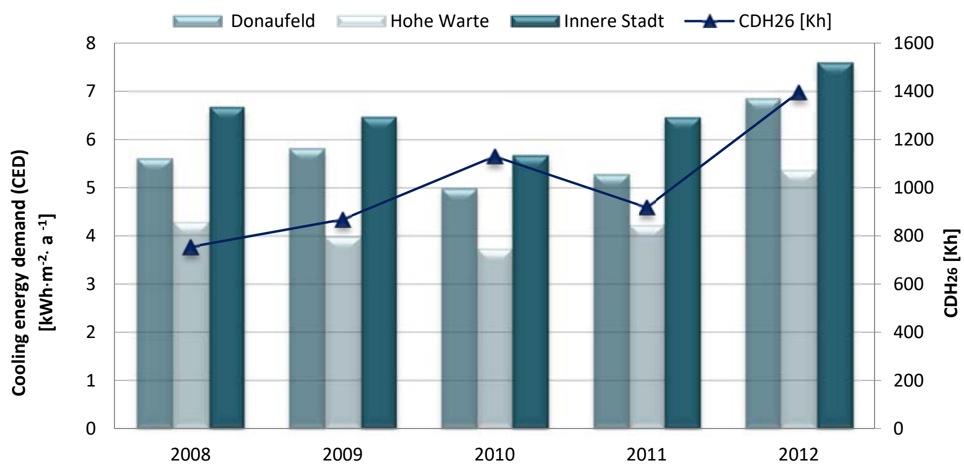

Figure 27 SFH – Variation of cooling energy demand over the years

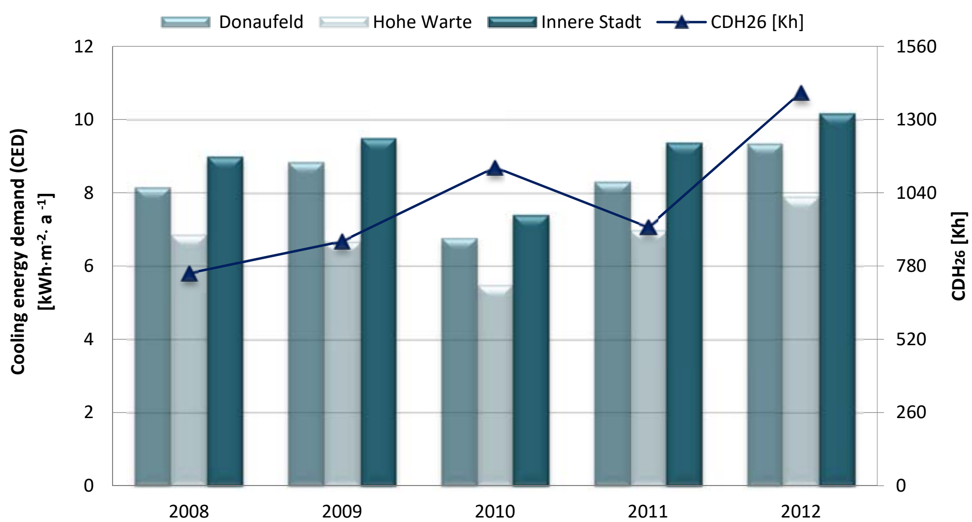

Figure 28 AB – Variation of cooling energy demand over the years

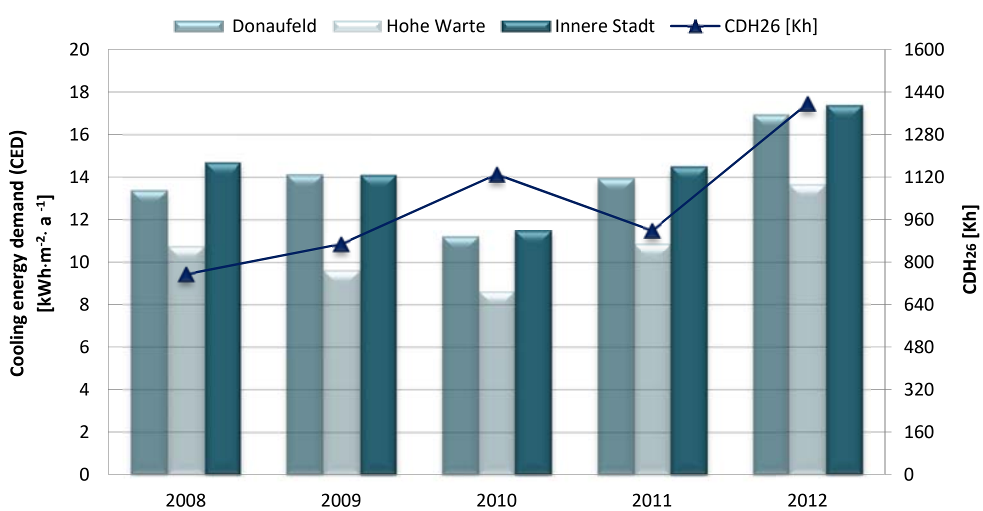

Figure 29 Office – Variation of cooling energy demand over the years

Variations of the weather data translate into important variations of buildings thermal performance according to the current study results (Table 3-4). At all location, the relative deviations of the maximum heating and cooling energy demand of the SFH, AB and Office from the corresponding minimum values (from 2008 to 2012) are considerable and the highest deviations are reached for AB (71% for HED) and Office (58% for CED).

Table 3-4 Heating (HED) and cooling (CED) energy demand for SFH, AB and Office for 3 different locations

Location	Year	SFH		AB		Office	
		HED	CED	HED	CED	HED	CED
		[kWh·m^{-2}· a $^{-1}$]					
Donaufeld	2008	26.7	5.6	12.1	8.2	44.0	13.4
	2009	32.1	5.8	17.0	8.8	54.0	14.2
	2010	36.8	5.0	19.9	6.8	60.3	11.2
	2011	31.7	5.3	15.8	8.3	52.1	14.0
	2012	31.2	6.9	15.5	9.4	51.9	17.0
	Max	36.8	6.9	19.9	9.4	60.3	17.0
	Min	26.7	5.0	12.1	6.8	44.0	11.2
	RD	*38%*	*38%*	*65%*	*38%*	*37%*	*51%*
	Mean	**31.7**	**5.7**	**16.0**	**8.3**	**52.5**	**13.9**
Hohe Warte	2008	29.2	4.3	13.6	6.9	51.9	10.8
	2009	33.9	4.0	18.3	6.7	56.8	9.6
	2010	38.1	3.7	20.5	5.5	62.6	8.6
	2011	32.1	4.2	15.9	7.0	52.7	10.9
	2012	32.1	5.4	16.1	7.9	53.1	13.7
	Max	38.1	5.4	20.5	7.9	62.6	13.7
	Min	29.2	3.7	13.6	5.5	51.9	8.6
	RD	30%	44%	50%	44%	21%	58%
	Mean	**33.1**	**4.3**	**16.9**	**6.8**	**55.4**	**10.7**
Innere Stadt	2008	24.2	6.7	10.6	9.0	40.9	14.7
	2009	30.2	6.5	15.7	9.5	51.3	14.1
	2010	34.0	5.7	18.2	7.4	57.1	11.5
	2011	28.5	6.5	14.1	9.4	48.2	14.5
	2012	28.4	7.6	14.1	10.2	48.4	17.4
	Max	34.0	7.6	18.2	10.2	57.1	17.4
	Min	24.2	5.7	10.6	7.4	40.9	11.5
	RD	*41%*	*34%*	*71%*	*37%*	*40%*	*51%*
	Mean	**29.1**	**6.6**	**14.6**	**9.1**	**49.2**	**14.5**
STD		**29.6**	**5.4**	**15.6**	**7.6**	**52**	**10.8**

Hohe Warte consistently displays the lowest annual mean temperature, the highest relative humidity and the strongest wind speeds (Table 3-1). In the same time, Hohe Warte showcases the lowest variation in HDD and the highest variation in CDH (Table 3-1). This might explain why Hohe Warte exhibits the lowest HED and the highest CED variations across the entire studied period. According to Leinich (2008), these variations could be even more considerable if one employs data from standard reference years from the past, thus leading to overestimation of future heating loads and underestimation of future cooling loads.

Figure 24 to Figure 26 show the HED variations for the studied buildings over the 5-year period together with their corresponding variations in HDD. A strong correlation between HED and HDD is revealed. This means that it could be possible to approximate future heating energy demands based on the HDD. Figure 27 to Figure 29 illustrate the CED variations of different buildings over the 5-year period together with the CDH. Their variations over the studied period are not correlated, leading to a difficult approximation of future CED. 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.

3.2.2 Thermal performance deviation from the standardized case

Heating and cooling energy demands obtained from simulations using weather data from meteorological stations are compared to the values obtained from the simulations using the reference weather file, commonly used for Vienna. Annual thermal performances for all locations and for the standardized case are presented in Table 3-4. Percent deviations of mean annual HED and CED from the standardized case are shown in Figure 30 and Figure 31. Monthly heating and cooling energy demands are included in Table 3-6 and Table 3-7 and their deviations from the standardized case are illustrated in Figure 34 to Figure 43.

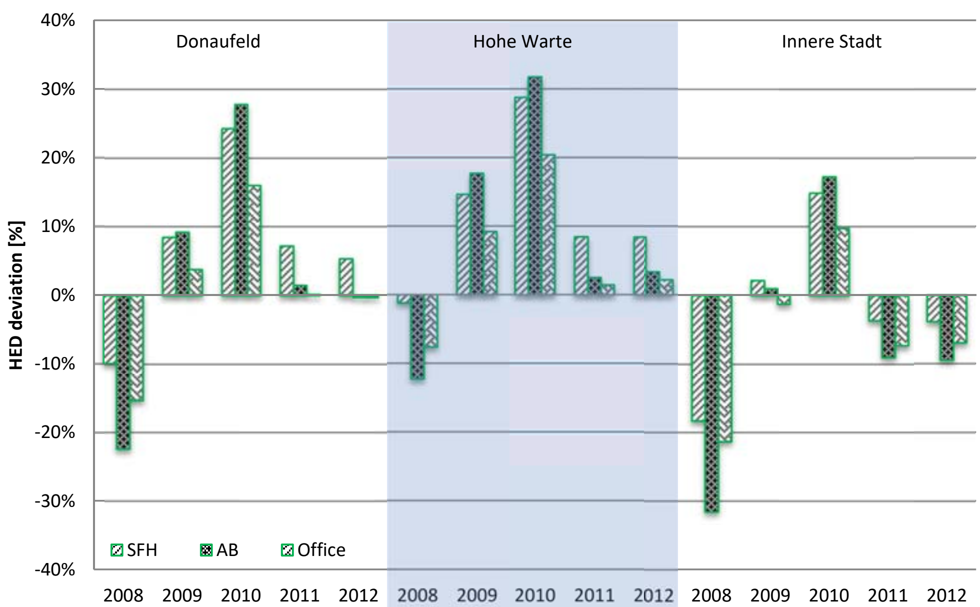

Figure 30 Mean annual HED percent deviations from the standardized case

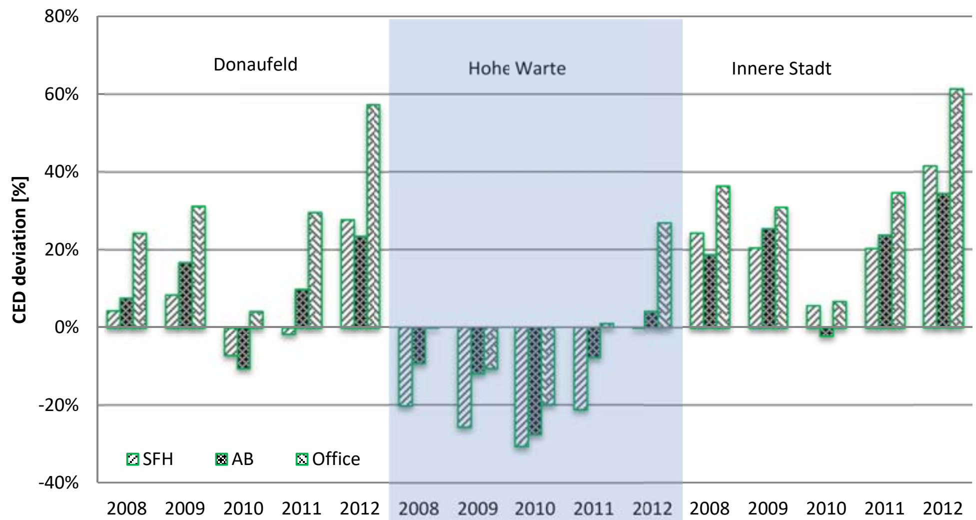

Figure 31 Mean annual CED percent deviations from the standardized case

Figure 30 shows no definitive trends in the local weather files versus standard reference weather file based heating performance of different buildings types across the different microclimates. For the studied 5-year period, initially, using the standard reference weather file one tends to overestimate the HED in 2008, only to underestimate it afterwards throughout in Donaufeld and Hohe Warte, and to overestimate it again for the Innere Stadt in the last 2 years. The degree to which the standard reference weather file underestimates or overestimates the performance is different from one year to another, from one microclimate to another, and ultimately, from one building type to another.

More or less, a similar pattern with Donaufeld is observed within Hohe Warte microclimate. The one that shows a significantly different behaviour is the Innere Stadt. Not only the pattern is very different from one year to another for all three types of buildings, changing from underestimation to overestimation, but also the degree of underestimation is much higher compared to the other locations. It could be speculated that this has to do with this specific microclimate having a significantly different type of heat island effect or wind tunnel effect versus Donaufeld and Hohe Warte (Allegrini et al. 2012).

Shown in Figure 31 are the deviations from the standard case of the mean annual CED. In general, the CED obtained when using the standard weather file are lower than the one using actual weather files for all years, exception making only one location: Hohe Warte. The office building in year 2012 shows the maximum CED deviation when using actual weather files versus standard file. The CED deviations, however, are less significant than the HED deviations.

The Table 3-5 summarizes the mean HED and CED of the 3 locations over the years and their relative deviations from the corresponding STD value for all 3 building types. The respective relative deviations are illustrated in Figure 32 and Figure 33 below.

Table 3-5 Relative deviation from STD file of the mean over the 3 locations for each year

Location	SFH		AB		Office	
	HED	CED	HED	CED	HED	CED
	[kWh·m^{-2}· a^{-1}]					
2008	26.7	5.5	12.1	8	45.6	13
2009	32.1	5.4	17	8.3	54	12.6
2010	36.3	4.8	19.5	6.6	60	10.5
2011	30.8	5.3	15.3	8.2	51	13.1
2012	30.6	6.6	15.2	9.1	51.1	16
STD	**29.6**	**5.4**	**15.6**	**7.6**	**52**	**10.8**
	RELATIVE DEVIATION					
2008	-10%	2%	-22%	5%	-12%	20%
2009	8%	0%	9%	9%	4%	17%
2010	23%	-11%	25%	-13%	15%	-3%
2011	4%	-2%	-2%	8%	-2%	21%
2012	3%	22%	-3%	20%	-2%	48%

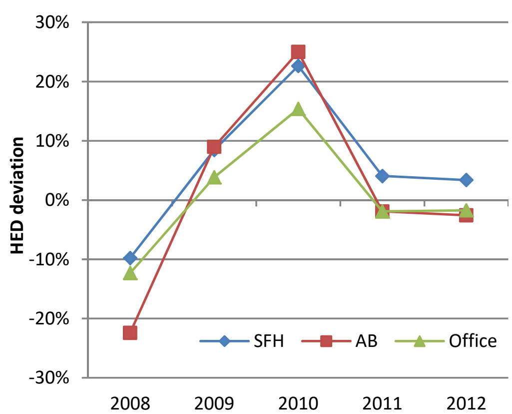

Figure 32 HED deviation [%] from STD case over 5 years

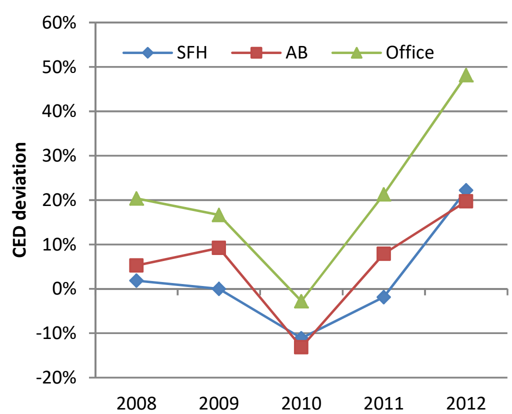

Figure 33 CED deviation [%] from STD case over 5 years

Both HED and CED have significant variations for almost all years. The degree of underestimation, when STD versus local weather file is used, is considerable for both HED and CED, reaching a maximum of 25% for HED and 48% for CED. The HED overestimation in 2008 could be explained by a warmer year than STD, while the CED overestimation in 2010 could be associated to a colder year than STD (Table 3-2).

Figure 34 to Figure 39 below show the deviations for the mean monthly HED from the standardized case. These values are calculated from Table 3-6. One observes a consistency in deviations trends from one location to another. However, while Donaufeld and Hohe Warte profiles have similar magnitudes of deviation, Innere Stadt stands out as different from them. Higher deviations are recorded for SFH and Office. In general, a pattern is fairly evident from one location to another for each month. The deviations have different monthly magnitudes and are different from one type of building to another. There is one month for all years, the month of October, where the heating loads for all buildings at all locations are underestimated when using the standard weather file. The most affected type of building is the Office, at location Hohe Warte.

Table 3-6 SFH Mean monthly HED for all years and locations [kWh·m^{-2}]

Location	Year	January	Feb.	March	April	May	Sept.	Oct.	Nov.	Dec.	Annual
Donaufeld	2008	6.5	4.7	3.4	1	0	0.3	1.3	3.4	6.2	26.7
	2009	8.3	6.4	3.9	0.2	0	0	1.9	4.2	7.2	32.1
	2010	9.3	6.9	3.8	1.2	0.1	0	2.7	3.5	9.3	36.8
	2011	7.3	6.4	3.8	0.3	0.1	0	1.9	5.7	6.3	31.7
	2012	6.3	7.9	2.6	1.2	0	0	1.5	4.2	7.5	31.2
Hohe Warte	2008	6.7	4.8	3.7	1.1	0	0.5	1.8	3.9	6.8	29.2
	2009	8.8	6.8	4.4	0.2	0	0	2.1	4.4	7.3	33.9
	2010	9.4	7	3.9	1.3	0.1	0.1	3.1	3.9	9.3	38.1
	2011	7.3	6.4	3.8	0.4	0.1	0	2.1	5.8	6.3	32.1
	2012	6.5	7.9	2.6	1.4	0	0	1.7	4.3	7.6	32.1
Innere Stadt	2008	5.9	3.9	3	0.6	0	0.3	1	3.3	6.2	24.2
	2009	8	6.2	3.9	0.1	0	0	1.5	3.7	6.7	30.2
	2010	8.8	6.5	3.4	0.9	0.1	0	2.3	3.4	8.7	34
	2011	6.7	5.9	3.2	0.2	0	0	1.5	5.3	5.8	28.5
	2012	6	7.5	2.2	1	0	0	1.1	3.7	6.9	28.5
STD		7.6	5.5	3.5	0.7	0.1	0	1	4.2	7.1	22.5

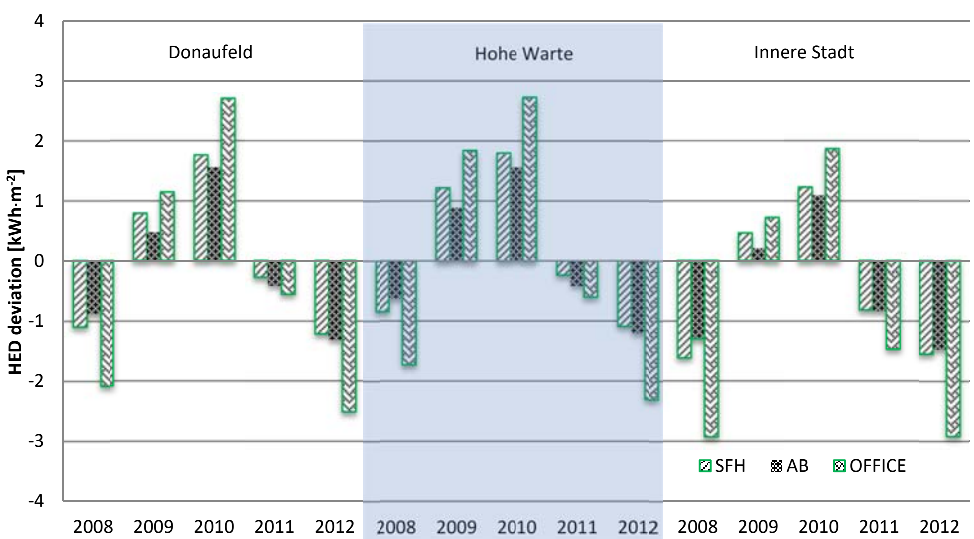

Figure 34 January - Mean monthly HED deviations from the standardized case

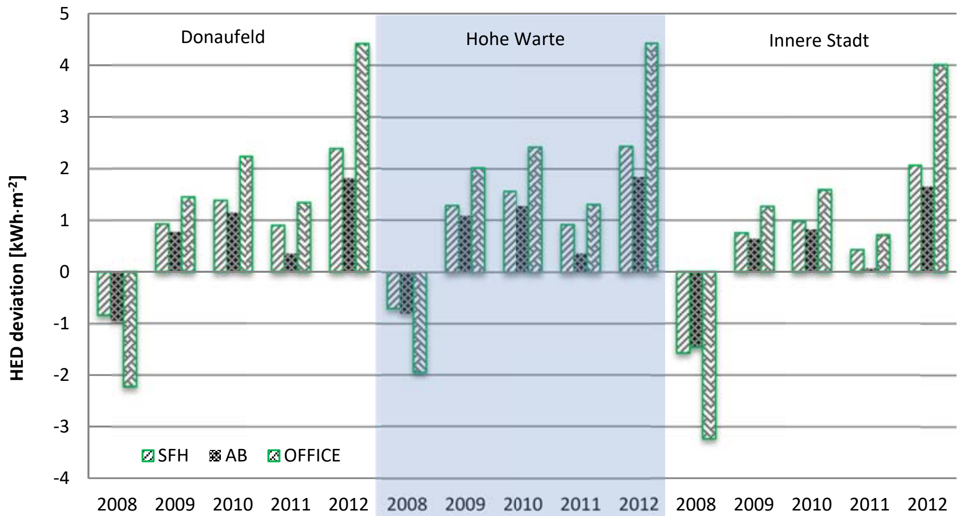

Figure 35 February - Mean monthly HED deviations from the standardized case

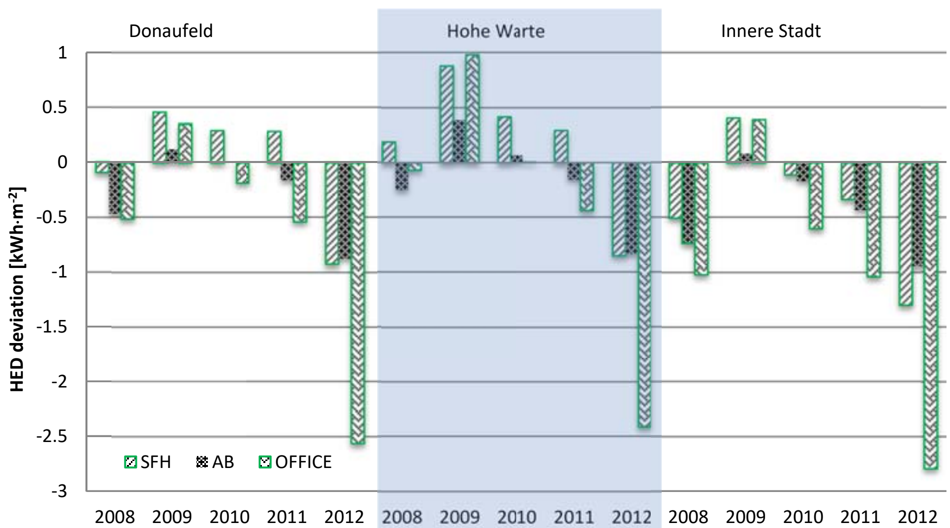

Figure 36 March - Mean monthly HED deviations from the standardized case

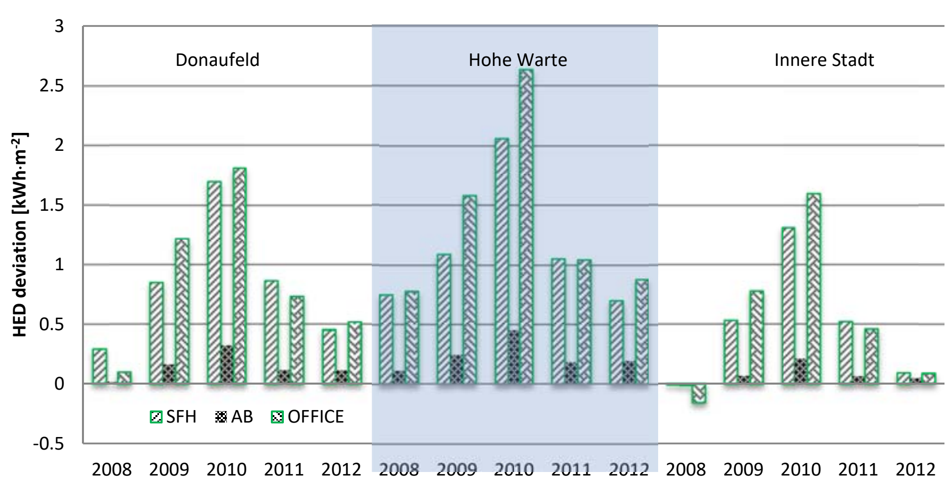

Figure 37 October - Mean monthly HED deviations from the standardized case

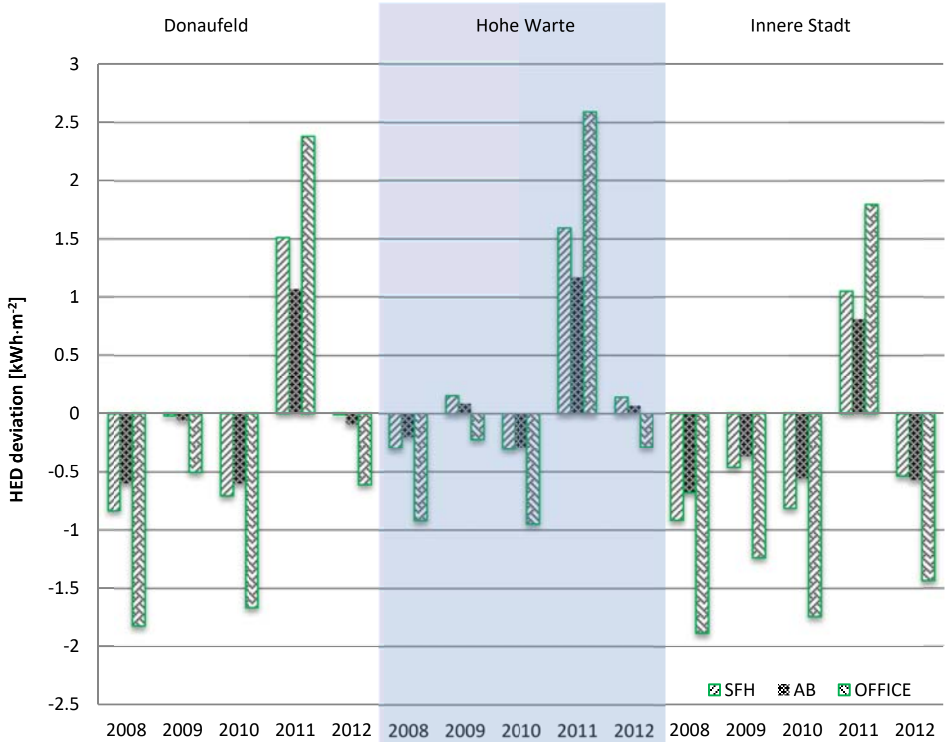

Figure 38 November - Mean monthly HED deviations from the standardized case

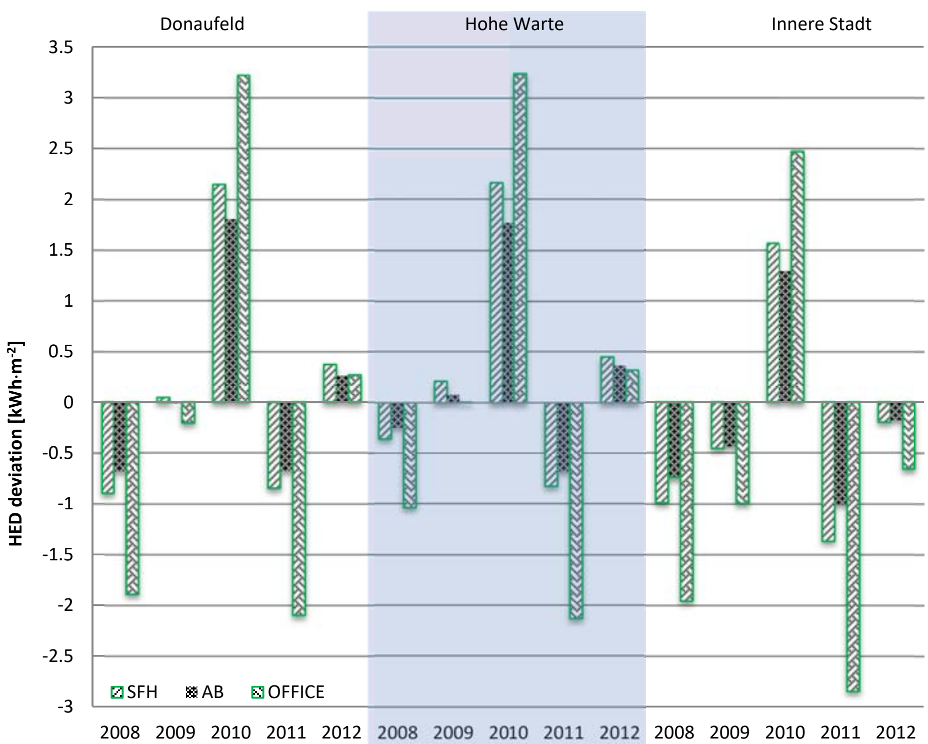

Figure 39 December - Mean monthly HED deviations from the standardized case

Figure 40 to Figure 43 show the deviations of the mean monthly CED from the standardized case. These values are calculated from Table 3-7. In this table only the monthly CED for SFH is presented, as an example.

In case of the deviations of monthly CED from the standardized case, Donaufeld and Innere Stadt show somewhat similar trend, having underestimated the CED for almost every month. The most affected building is the Office at location Innere Stadt during the month of July. On the other side, at Hohe Warte location, the CED is usually overestimated for all buildings, with the peak being attained in June for the Office.

All these observations would reconfirm the fact that accumulations of heat occur in the densely built-up areas, such as Innere Stadt (Mahdavi et al. 2013). Therefore, underestimations of the CED at this location could take place when standard weather files are used for building energy simulations. The same situation applies to Donaufeld, but arguably for different reasons: this is a flat urban area missing trees (shadow) that does not receive much ventilation because of the low wind speeds. Lastly, Hohe Warte is a green district, up on the hill, close to Vienna woods, with tall trees that are broadly present pretty much everywhere (Stiles et al. 2014) explaining the overestimation of the CED when using standard weather files in building energy simulations (Orehounig et al. 2011).

Table 3-7 SFH Mean monthly CED for all years and locations [kWh·m^{-2}]

Location	Year	March	April	May	June	July	August	September	October	Annual
Donaufeld	2008	0	0	0.3	1.6	1.6	1.4	0.6	0.1	5.6
	2009	0	0.2	0.4	0.5	2.1	2	0.5	0.1	5.8
	2010	0	0.1	0.1	0.8	2.6	1.2	0.2	0.1	5.1
	2011	0.1	0.1	0.3	1.2	1.2	1.5	0.7	0.2	5.3
	2012	0.1	0.1	0.4	1.4	2.2	2.1	0.4	0.1	6.8
Hohe Warte	2008	0	0	0.2	1.3	1.2	1	0.4	0.1	4.2
	2009	0	0.2	0.3	0.3	1.5	1.4	0.3	0.1	4.1
	2010	0	0.1	0.1	0.6	2	0.7	0.1	0.1	3.7
	2011	0.1	0.1	0.3	1	0.9	1.2	0.5	0.1	4.2
	2012	0.1	0	0.3	1	1.8	1.7	0.3	0.1	5.3
Innere Stadt	2008	0	0.1	0.4	1.9	1.7	1.7	0.8	0.1	6.7
	2009	0	0.3	0.5	0.6	2.3	2.2	0.6	0.1	6.6
	2010	0	0.1	0.1	1	3	1.3	0.1	0.1	5.7
	2011	0.1	0.1	0.6	1.5	1.3	1.9	0.8	0.2	6.5
	2012	0.1	0.1	0.5	1.4	2.3	2.6	0.5	0.1	7.6
STD		0	0.1	0.4	1.4	1.6	1.5	0.3	0.1	5.4

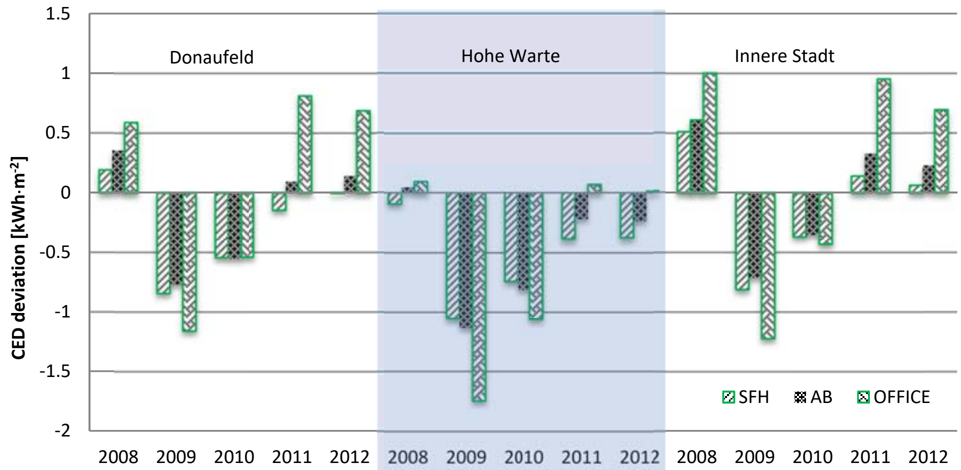

Figure 40 June - Mean monthly CED deviations from the standardized case

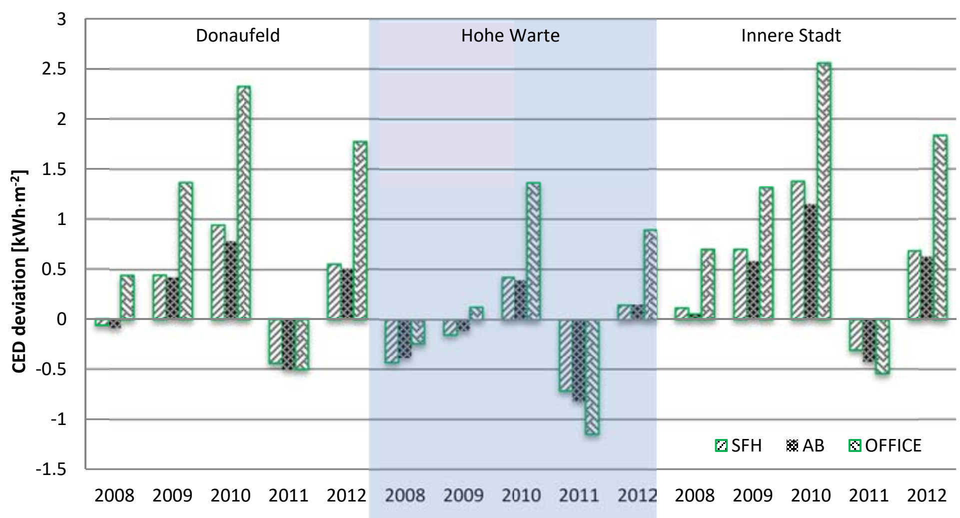

Figure 41 July - Mean monthly CED deviations from the standardized case

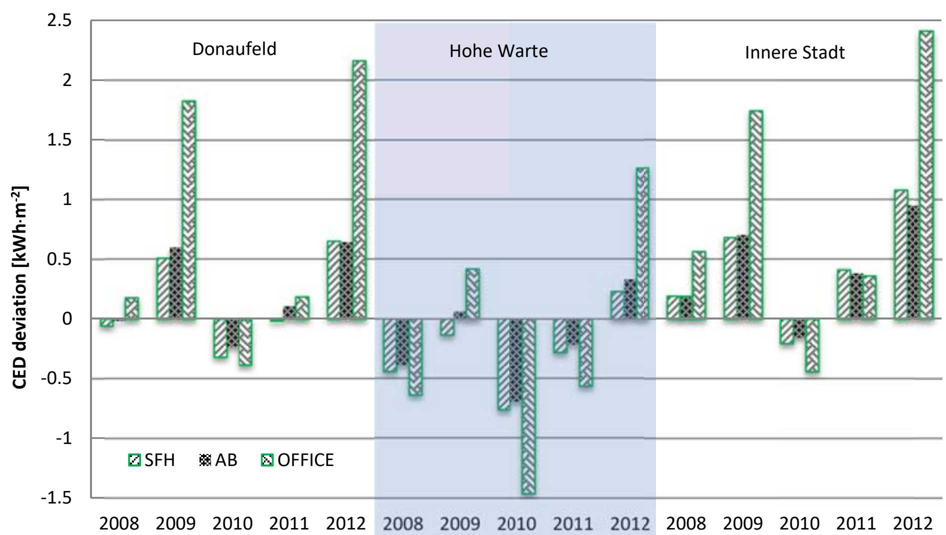

Figure 42 August - Mean monthly CED deviations from the standardized case

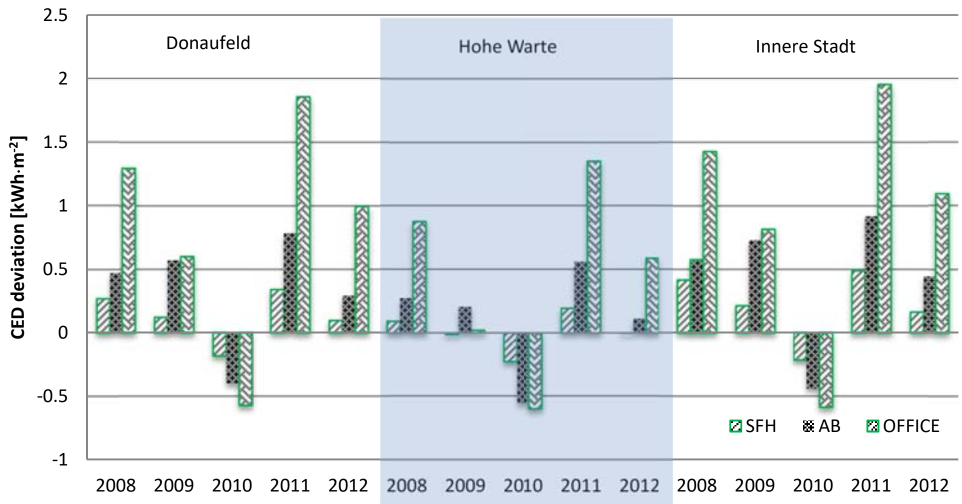

Figure 43 September - Mean monthly CED deviations from the standardized case

3.3 Spatial results: Thermal performance variation at different locations

Cities like Vienna encompass many different microclimates (Mahdavi et al 2011). According to the analysis of weather factors (e.g. temperature, wind speed) at IS, HW and Donaufeld, the considerable variations that occur among these locations should be addressed and their possible impact on thermal performance in buildings should be evaluated accordingly in order to answer the following research question: **how does the buildings' thermal performance vary depending on the location in the city?**

Table 3-4 above presents the simulation results for heating (HED) and cooling (CED) energy demands for SFH, AB and Office for 3 locations in Vienna, Donaufeld (D), Hohe Warte (HW) and Innere Stadt (IS), and their variations are illustrated in Figure 44 to Figure 46.

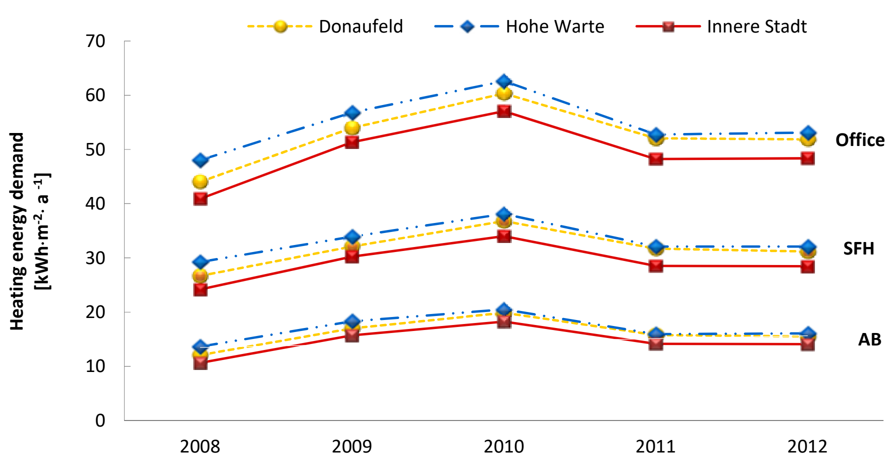

Figure 44 Variation of HED over a 5 year-period for all buildings

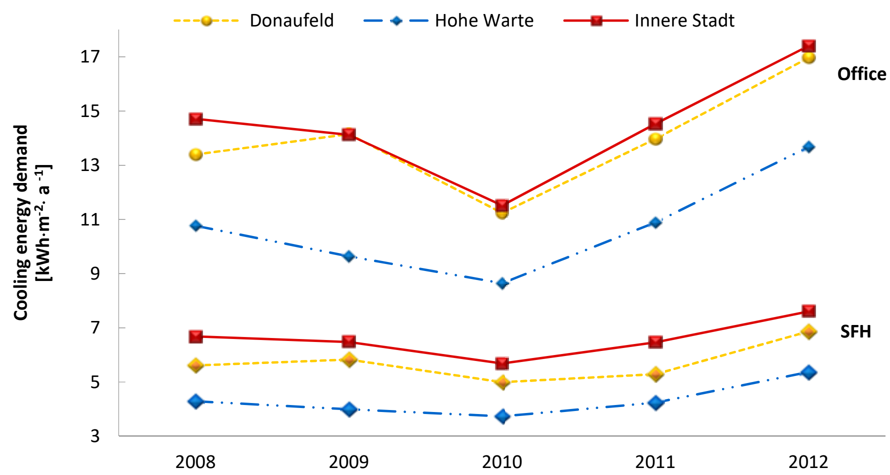

Figure 45 Variation of CED over a 5 year-period for SFH and Office

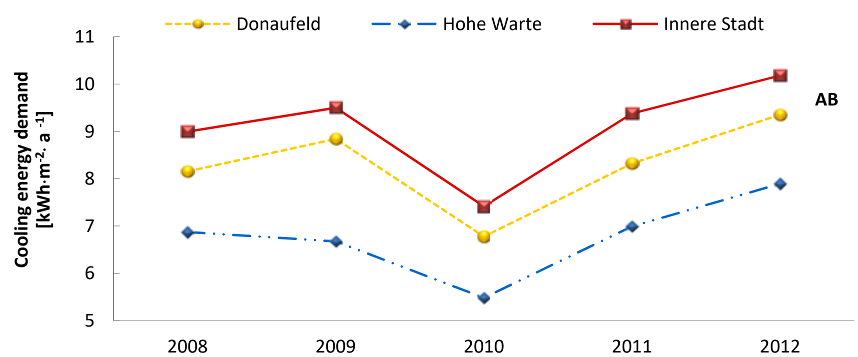

Figure 46 Variation of CED over a 5 year-period for AB

From Figure 44 to Figure 46, it can be observed that the lowest HED demand is achieved by AB, independent of the year and the location, while the highest HED is obtained in the Office. Looking at the same year but different locations, one notices an important variation in thermal performance. Innere Stadt requires significantly less heating energy versus Donaufeld and Hohe Warte respectively. These results could be due to the existence of urban heat island effect in city centers like Innere Stadt. Table 3-1 shows consistent higher temperatures in the city centre (Innere Stadt) compared to the other two locations. According to Table 3-3, CED has a bigger variation from one location to another compared to HED. In the same table it can be observed that Hohe Warte has the highest HED and the lowest CED which could be because of the cooling effect of the wooded hills in the proximity. The moderate cooling effect of high proportion of water areas, low-rise vegetation and low winds could explain the moderate thermal performance at Donaufeld. Alternatively, the heating effect of a sealed and dense city centre corroborated with high temperatures might be the reason for the buildings' highest HED and lowest CED at Innere Stadt (Stiles et al. 2014).

The Table 3-8 summarizes the mean HED and CED of the 5-year period for the 3 locations and their relative deviations from the corresponding STD value for all 3 building types. The respective relative deviations are illustrated in Figure 47 and Figure 48 below.

Table 3-8 Relative deviation from STD file of the mean over the 5-year period

Location	SFH		AB		Office	
	HED	CED	HED	CED	HED	CED
	[kWh·m^{-2}· a^{-1}]					
Donaufeld	31.7	5.7	16	8.3	52.5	13.9
Hohe Warte	33.1	4.3	16.9	6.8	55.4	10.7
Innere Stadt	29.1	6.6	14.6	9.1	49.2	14.5
STD	**29.6**	**5.4**	**15.6**	**7.6**	**52**	**10.8**
RELATIVE DEVIATION						
Donaufeld (D)	7%	6%	3%	9%	1%	29%
Hohe Warte (HW)	12%	-20%	8%	-11%	7%	-1%
Innere Stadt (IS)	-2%	22%	-6%	20%	-5%	34%

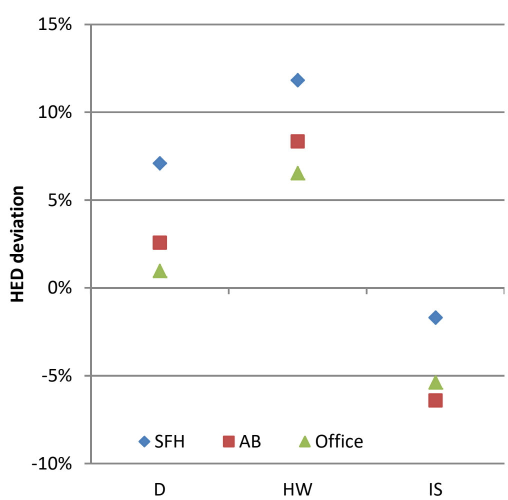

Figure 47 HED deviation [%] from STD case at different locations

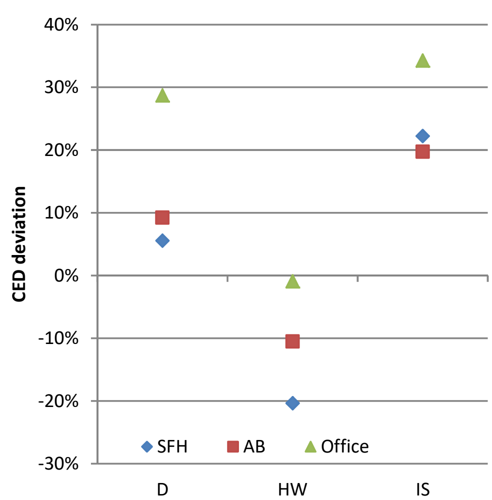

Figure 48 CED deviation [%] from STD case at different locations

At Donaufeld, when STD versus local weather file is used, HED is slightly underestimated for all buildings while CED is underestimated by a maximum of 29% (for Office).

At Hohe Warte, when STD versus local weather file is used, HED is underestimated by a maximum of 12% (for SFH) and CED is overestimated by a maximum of 20% (for SFH) (because of a local colder location than the STD according to Table 3-1).

At Innere Stadt, when STD versus local weather file is used, HED is mildly overestimated (because of a local warmer location than the STD according to Table 3-1) while CED is underestimated by 34% (for Office) and 20% (for AB).

3.4 Different types of buildings thermal performance variation

According to “Statistisches Jahrbuch der Stadt Wien 2015” (MA23 2015), the share of built-up area within each district is considerable. Figure 49 illustrates the land use by district.

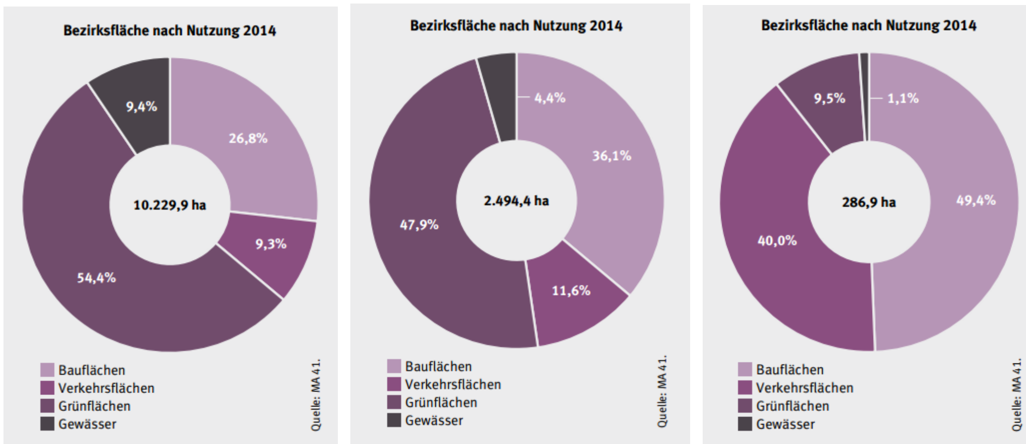

Figure 49 Land use at Döbling, Donaustadt and Innere Stadt (from left to right)

The types of buildings in Vienna vary greatly by district. In Donaufeld (which is part of Donaustadt district) the predominant residential buildings are single family houses (80%) and low rise apartment blocks (13%). In Döbling district, where Hohe Warte is situated, there is an equal distribution of single family houses and multi-family houses (more than 3 apartments/ building) counting each for around 45% of the total residential stock of this district. In Innere Stadt, single family houses are extremely rare (28 out of 801 residential buildings in 2011).This district features mostly perimeter apartment blocks with a minimum of 4 stories used as offices (67% of total non-residential buildings) and multi-family buildings (97% of the residential buildings) (Statistics Austria 2013).

When it comes to office buildings the highest distribution is encountered in Innere Stadt, followed by Döbling (Hohe Warte), and Donaustadt (Donaufeld) corresponding to 62%, 33% and 26% , respectively, out of the total non-residential stock.

The question is: **how does the buildings’ thermal performance vary depending on the type of building?**

The HED and CED and their relative deviations (maximum from the minimum values) are presented in Table 3-3 above and illustrated in Figure 44 to Figure 46 for three different types of buildings: SFH, AB and Office.

The impact of the weather variations on thermal performance differs from one type of building to another. According to the results from Table 3-3, all buildings achieve low and similar variations in heating demand, but high magnitudes of variations in cooling demand from one location to another. Among them, the highest variations are observed at SFH. This explained by the fact that small buildings are very sensitive to variations in climate because of low V/A ratio, meaning that the greater the building envelope area, the more heat gain/loss occurs through it (Xu P et al. 2012). In the case of the buildings that are subject to this research, SFH has the lowest characteristic length (1.36 m^3/m^2), followed by AB (3.18 m^3/m^2) and Office (4.07 m^3/m^2).

The AB has the lowest HED value (Figure 44), but the highest HED variation (Table 3-4) across all years. On the other hand, SFH and Office have higher HED values that correspond to low HED variations at different locations. This would lead to the conclusion that low energy buildings (AB in our case) are more sensitive to differences in microclimate, as mentioned in other previous studies (Wang et al. 2009).

For all buildings, CED's considerable variation suggests an increased importance of using actual microclimate conditions in energy simulations.

4 CONCLUSION

The findings of the current research demonstrate that there is a significant range of variations in the simulated HED and CED using local weather files versus the standard weather file usually employed for building energy simulations for Vienna.

Over the studied 5-year period, a considerable underestimation of the HED and CED can be noticed when STD file is employed. The degree of underestimation is the highest for CED, reaching up to 48% in 2012 (for Office). HED underestimation is also important reaching a maximum of 25% in 2010 (for AB). In only one year, both HED and CED overestimations could be explained by an abnormal warmer or colder weather than usual.

Depending on the location, both HED and CED variations occur, when using STD weather file versus local ones. The overestimations for HED and CED are due to particular conditions of a certain location (e.g. hot city center at low altitude with very little vegetation as in Innere Stadt or high altitude green urban area as in Hohe Warte).

Even more, the data shows that no local weather file out of the 3 studied locations could be used to predict the energy demand for the other 2 locations.

Each type of building (SFH, AB, and Office) shows great HED and CED variations when STD versus local weather file is used. Not using the local weather files in predicting the energy demand of future constructions could lead to serious consequences in terms of building overdesign (i.e. waste of materials) or underdesigned (i.e. waste of energy). For optimum energy consumption, it is recommended that each type of building be designed and built by adjusting the minimum construction requirements to fit the local microclimate conditions. Urban planners should therefor acknowledge the microclimate impact and use it when approving the new building projects.

Some new insights and possible trends might be observed if the same analysis is performed for a much longer period of time for all 3 buildings at more locations. This could be useful in understanding the specific microclimate features that have the biggest impact on thermal performance of different types of buildings and how to optimize the energy consumption of new constructions while minimizing the greenhouse gas emissions.

Lastly, the simulated CED shows a poor correlation with the CDH (Figure 27 to Figure 29). Further research into estimating CDH as a function of other climate factors such as humidity, solar radiation, and wind speed (alongside temperature) could improve this correlation resulting in better CED predictions.

5 INDEX

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APPENDIX

A. Construction elements and plans for research models

1. SFH

Table A-1 SFH materials

Construction elements SFH			Total Width	Density	Thermal conductivity	Specific Heat	Vapor diffusion factor
Element	**Material**	**Thickness [mm]**	**d [mm]**	**[kg/m³]**	**λ [W/mK]**	**[J/mK]**	
External wall	Lime-Cement Plaster	15	367	1600	0.83	1000	10
	Brick	250		940	0.277	1000	8
U = 0.292 W/m²K	EPS	100		15	0.04	1450	60
Uvalue = 0.350 W/m²K	Reinforced silicate plaster	2		1750	0.8	1000	40
Internal Floor	Plywood Floor	18	362	500	0.13	1600	50
Roof/Internal Ceiling	Mineral wool in timber frame	180		18	0.038	1030	1
First Floor	PE	1.7		980	0.5	1260	100000
U = 0.200 W/m²K	Reinforced concrete slab, 2% steel	150		2400	2.5	1000	130
Uvalue = 0.200 W/m²K	Plasterboard	12.5		700	0.21	1000	10
Internal Floor/Internal Ceiling	Hardwood	22	515	740	0.16	1600	200
	Cement Screed	50		2000	1.6	1000	15
	Reinforced concrete slab	150		2400	2.5	1000	130
	Air Layer	130		1.2	0.813	1000	1
U = 0.238 W/m²K	Mineral wool	150		18	0.038	1030	1
N/A	Plasterboard	12.5		700	0.21	1000	10
Ground Floor	Hardwood	22	477	740	0.16	1600	200
	Cement Screed	50		2000	1.6	1000	15
	XPS	100		38	0.039	1450	200
	Bitumen aluminium foil	4		1100	0.23	1260	36000
	Reinforced concrete slab	150		2400	2.5	1000	130
	Building Paper Felt	0.3		500	0.17	1500	9999
U = 0.348 W/m²K	Sand blinding	150		2240	1.3	980	34
Uvalue = 0.400 W/m²K	PP Non woven filter cloth	0.2		600	0.22	792	37500
Exposed floor / Internal ceiling (Terrase)	Terrazzo Tiles	50	605	2400	1.75	850	48
	Sand blinding	50		920	1.3	2240	34
	Crumb rubber mat	10		780	0.17	1360	2.3
	Bitumen dichtungsbahn	7.8		1100	0.23	1260	102000
	PE	1.6		980	0.5	1260	100000
	EPS 25	40		25	0.036	1400	60
	Bitumen aluminium foil	1.4		1100	0.23	1260	102000
	PE	1.7		980	0.5	1260	100000
	Reinforced concrete slab, 2% steel	150		2400	2.5	1000	130
	Air Layer	130		1.2	0.813	1000	1
U = 0.190 W/m²K	Mineral wool	150		18	0.038	1030	1
Uvalue = 0.200 W/m²K	Plasterboard	12.5		700	0.21	1000	10
Internal wall	Lime-Cement Plaster	15	250	1600	0.83	1000	10
	Brick	200		850	0.314	1000	8
	Lime-Cement Plaster	15		1600	0.83	1000	10
Internal wall non-structural	Lime-Cement Plaster	15	150	1600	0.83	1000	10
	Brick	120		800	0.34	1000	8
	Lime-Cement Plaster	15		1600	0.83	1000	10
Roof	Clay roof tiles		284				
	PE Tyvek	0.6		325	0.42	1500	66
	Plywood Sheathing	16		500	0.13	1600	50
	Mineral wool in timber frame	90		18	0.038	1030	1
	Mineral wool in timber frame	90		18	0.038	1030	1
	Chipboard	18		650	0.13	1700	50
	PE	1.7		980	0.5	1260	100000
U = 0.170 W/m²K	Glass wool	50		24	0.039	920	1.5
Uvalue = 0.200 W/m²K	Plywood	18		500	0.13	1600	50

Window	**Triple glazing, Ar, low-e, 4-12-4-12-4**	***Ug = 0.900 W/m²K***
	Softwood frame	***Uf = 1.510 W/m²K***
Uw = 1.300 W/m²K	**Linear thermal transmittance coef.**	***PSI = 0.050 W/mK***
Uvalue = 1.400 W/m²K		
Entrance Door	**Hardwood**	**78**
Ud = 1.660 W/m²K		
Uvalue = 1.700 W/m²K		

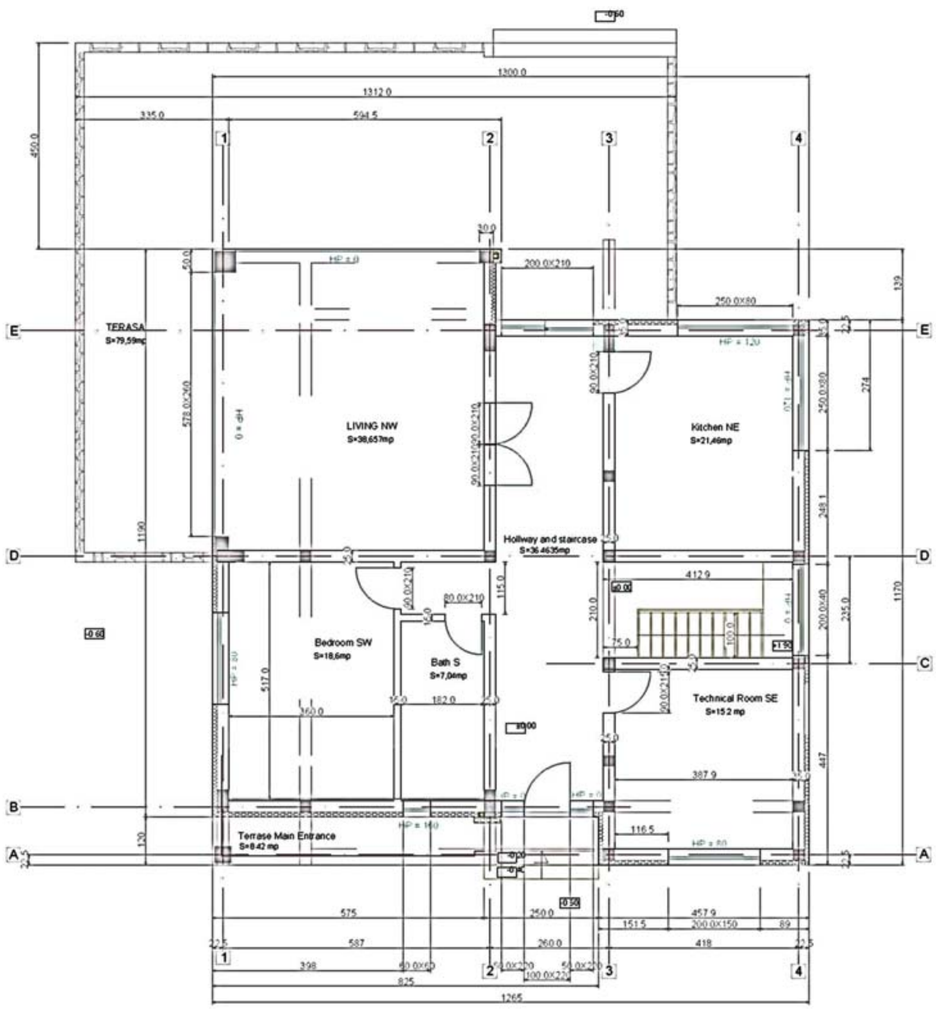

Figure A1 SFH Ground Floor Plan

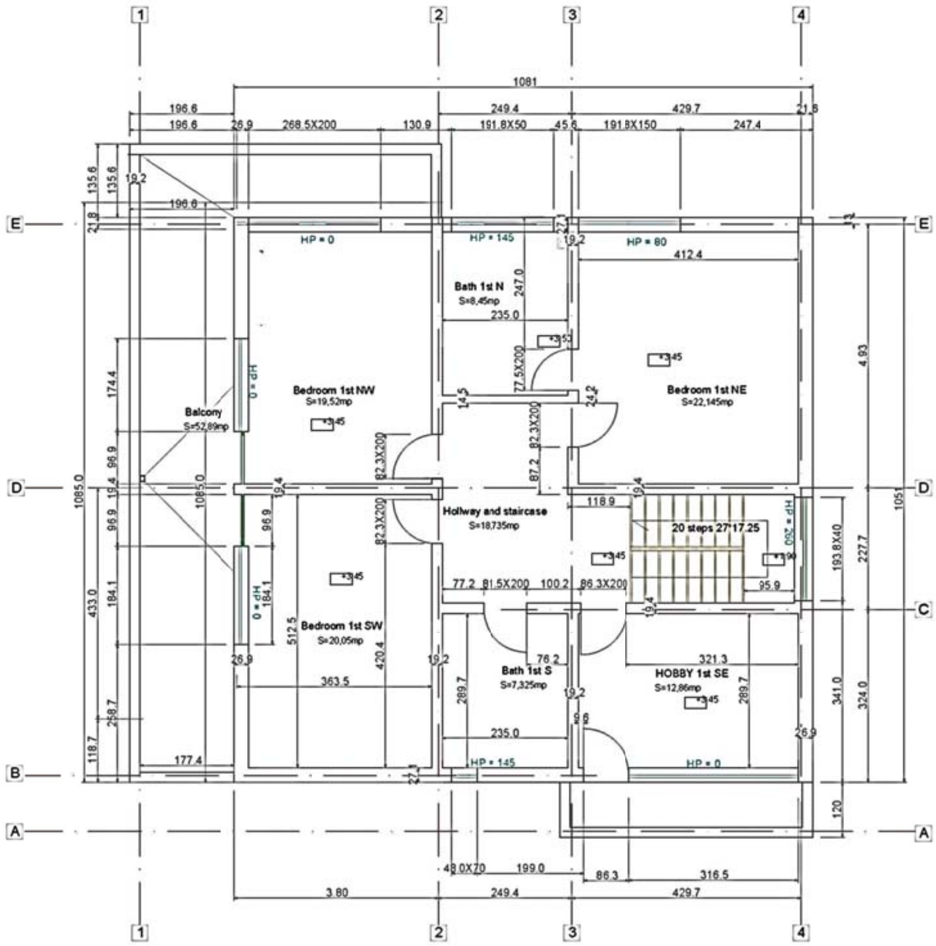

Figure A2 SFH First Floor Plan

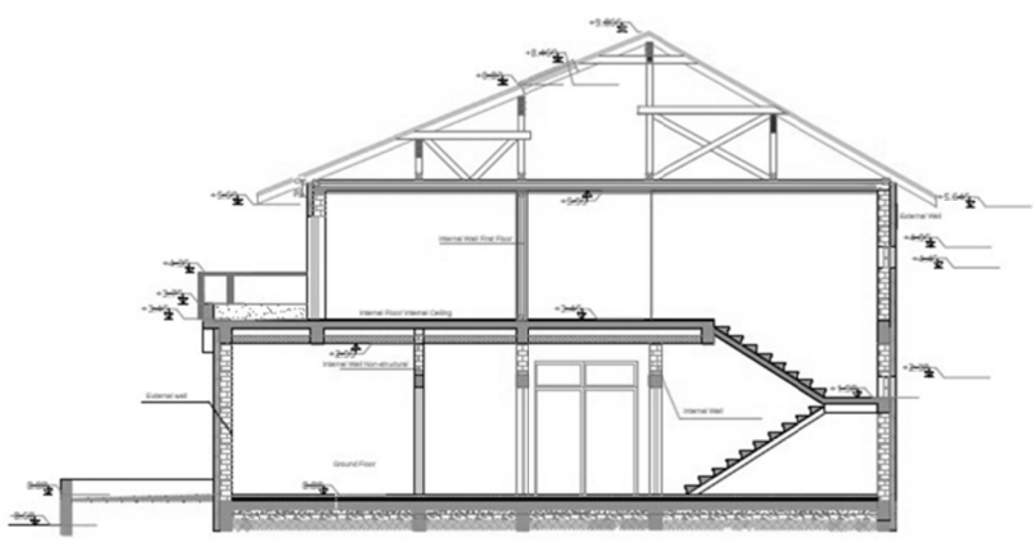

Figure A3 SFH Section

2. AB

Table A-2 AB materials

Construction elements AB			Total Width	Density	Thermal conductivity	Specific Heat	Vapor diffusion factor
Element	**Material**	**Thickness [mm]**	**d [mm]**	**[kg/m^3]**	**λ [W/mK]**	**[J/mK]**	
External wall	Concrete	200		1800	0.85	1000	50
	EPS W 20	100	378	20	0.038	1450	40
U = 0.348 W/m^2K	Concrete	65		1800	0.85	1000	50
Uvalue = 0.350 W/m^2K	Paster dence	13		1700	0.7	1000	50
Underground external wall (ground)	Concrete	200		1800	0.85	1000	50
	Bitumen waterproofing foil	1.6	302	1100	0.23	1260	100000
U = 0.305 W/m^2K	XPS	100		33	0.033	1380	100
Uvalue = 0.400 W/m^2K	PP Non woven filter cloth	0.2		600	0.22	792	37500
Internal Floor / Internal Ceiling Underground or Garage	Ceramic tiles	10		500	0.13	1600	50
	Cement Screed	50		2000	1.6	1000	15
	PE	0.2	380	980	0.5	1260	100000
	Acoustic insulation board	20		11	0.033	1450	30
U = 0.296 W/m^2K	EPS W 20	100		20	0.038	1450	40
Uvalue = 0.300 W/m^2K	Reinforced concrete slab, 2% steel	200		2400	2.5	1000	130
Underground slab (ground)	Cement Screed	50		2000	1.6	1000	15
	Reinforced concrete slab	150		2400	2.5	1000	130
	PE	0.2		980	0.5	1260	100000
	EPS	90	441	25	0.036	1400	60
	Building Paper Felt	0.2		500	0.17	1500	9999
U = 0.388 W/m^2K	Sand blinding	150		2240	1.3	980	34
Uvalue = 0.400 W/m^2K	PP Non woven filter cloth	0.2		600	0.22	792	37500
Underground Garage Ceiling/ Courtyard	Terrazzo Tiles	50		2400	1.75	850	48
	Sand blinding	50		920	1.3	2240	34
	Crumb rubber mat	10		780	0.17	1360	2.3
	Bitumen dichtungsbahn	7.8		1100	0.23	1260	102000
	PE	1.6	562	980	0.5	1260	100000
	Reinforced concrete slab, 2% steel	150		2400	2.5	1000	130
	Air Layer	130		1.2	0.813	1000	1
U = 0.241 W/m^2K	Mineral wool	150		18	0.038	1030	1
Uvalue = 0.400 W/m^2K	Plasterboard	12.5		700	0.21	1000	10
Internal Floor/Internal Ceiling	Ceramic tiles	10		740	0.16	1600	200
	Cement Screed	50		2000	1.6	1000	15
	Reinforced concrete slab	150		2400	2.5	1000	130
	Air Layer	50	323	1.2	0.813	1000	1
U = 0.238 W/m^2K	Mineral wool	50		18	0.038	1030	1
N/A	Plasterboard	12.5		700	0.21	1000	10
Partition wall (between apartments)	Lime-Cement Plaster	15		1600	0.83	1000	10
	Accoustic insulation	20		11	0.033	1450	30
	Brick	125	195	850	0.314	1000	8
U = 0.194 W/m^2K	Accoustic insulation	20		11	0.033	1450	30
Uvalue = 0.900 W/m^2K	Lime-Cement Plaster	15		1600	0.83	1000	10
Apartment Wall to unheated space	Lime-Cement Plaster	15		1600	0.83	1000	10
	Concrete	100		1800	0.85	1000	50
	EPS W 20	70	225	20	0.038	1450	40
U = 0.525 W/m^2K	Concrete	25		1800	0.85	1000	50
Uvalue = 0.600 W/m^2K	Lime-Cement Plaster	15		1600	0.83	1000	10
	Lime-Cement Plaster	15		1600	0.83	1000	10
Wall uninsulated	Brick	120	150	800	0.34	1000	8
	Lime-Cement Plaster	15		1600	0.83	1000	10
Roof	Metal roof						
	PE Tyvek	0.6		325	0.42	1500	66
	Plywood Sheathing	16		500	0.13	1600	50
	Mineral wool in timber frame	40		18	0.045	1030	1
	Mineral wool in timber frame	120	382	18	0.038	1030	1
	Mineral wool in timber frame	40		18	0.038	1030	1
U = 0.194 W/m^2K	Reinforced concrete slab, 2% steel	150		2400	2.5	1000	130
Uvalue = 0.200 W/m^2K	Lime-Cement Plaster	15		1600	0.83	1000	10
Roof_flat	Sand blinding	50					
	Bitumen dichtungsbahn	7.8		1100	0.23	1260	102000
	XPS	30		33	0.033	1380	100
	PE	1.6	452	980	0.5	1260	100000
	Reinforced concrete slab, 2% steel	150		2400	2.5	1000	130
	Air Layer	50		1.2	0.813	1000	1
U = 0.191 W/m^2K	Mineral wool	150		18	0.038	1030	1
Uvalue = 0.200 W/m^2K	Plasterboard	12.5		700	0.21	1000	10

Vehicle access door	Aluminium foil	0.5	15	2800	160	880	100000
U = 2.220 W/m²K	EPS	13.5		10	0.04	1450	60
Uvalue = 2.500 W/m²K	Aluminium foil	0.5		2800	160	880	100000

Window	Triple glazing, Ar, low-e, 4-12-4-12-4	*Ug = 0.900 W/m²K*
	Softwood frame	*Uf = 1.510 W/m²K*
Uw = 1.300 W/m²K	Linear thermal transmittance coef.	*PSI = 0.050 W/mK*
Uvalue = 1.400 W/m²K		
Entrance Door	Double glazing, Ar, low-e, 4-12-4	*Ug = 1.500 W/m²K*
Ud = 1.600 W/m²K	Softwood frame	*Uf = 1.510 W/m²K*
Uvalue = 1.700 W/m²K	Linear thermal transmittance coef.	*PSI = 0.050 W/mK*

Figure A4 AB Ground Floor

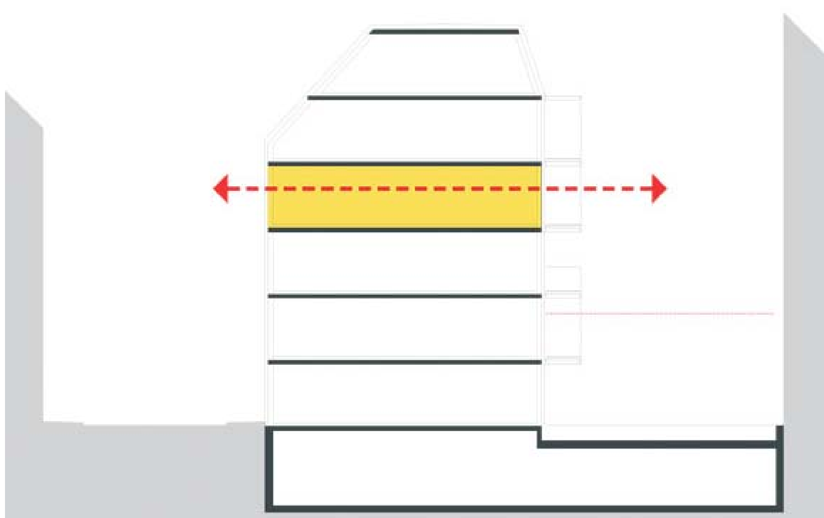

Figure A5 AB NS Section

Figure A6 AB First, Second and Third Floor TYP

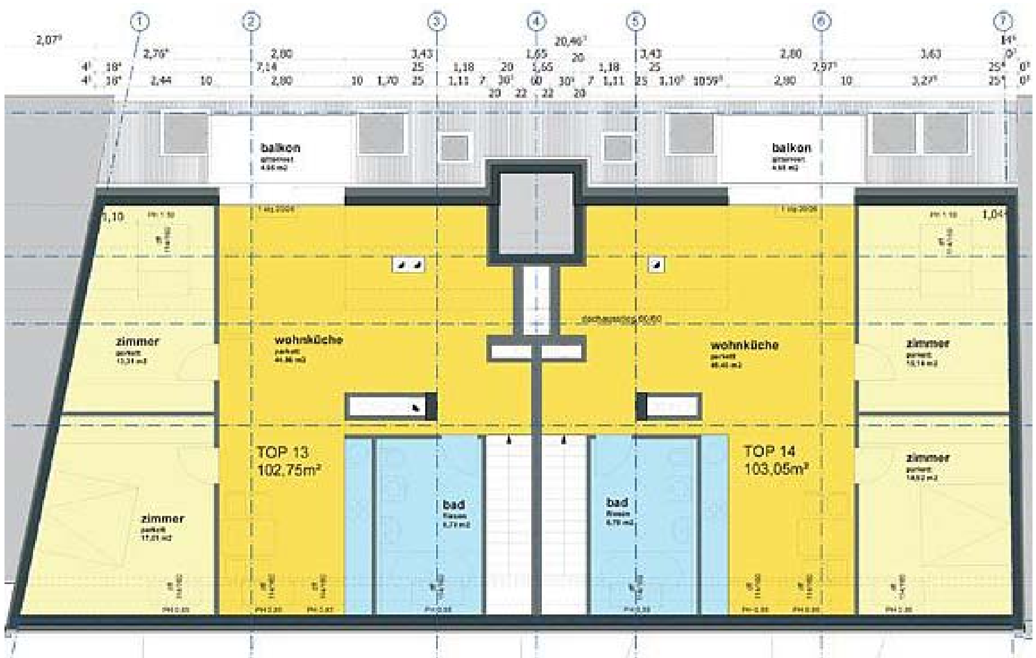

Figure A7 AB - Attic

3. Office

Table A-3 Office materials

Construction elements OFFICE			Total Width	Density	Thermal conductivity	Specific Heat	Vapor diffusion factor
Element	Material	Thickness [mm]	d [mm]	[kg/m^3]	λ [W/mK]	[J/mK]	
External wall	Concrete	200	378	1800	0.85	1000	50
	EPS W 20	100		20	0.038	1450	40
U = 0.348 W/m^{2}K	Concrete	65		1800	0.85	1000	50
Uvalue = 0.350 W/m^{2}K	Paster dence	13		1700	0.7	1000	50
Underground external wall	Concrete	200	302	1800	0.85	1000	50
(ground)	Bitumen waterproofing foil	1.6		1100	0.23	1260	100000
U = 0.305 W/m^{2}K	XPS	100		33	0.033	1380	100
Uvalue = 0.400 W/m^{2}K	PP Non woven filter cloth	0.2		600	0.22	792	37500
Internal Floor / Internal Ceiling Underground or Garage	Ceramic tiles	10	380	500	0.13	1600	50
	Cement Screed	50		2000	1.6	1000	15
	PE	0.2		980	0.5	1260	100000
	Acoustic insulation board	20		11	0.033	1450	30
U = 0.296 W/m^{2}K	EPS W 20	100		20	0.038	1450	40
Uvalue = 0.300 W/m^{2}K	Reinforced concrete slab, 2% steel	200		2400	2.5	1000	130
Underground slab (ground)	Cement Screed	50	441	2000	1.6	1000	15
	Reinforced concrete slab	150		2400	2.5	1000	130
	PE	0.2		980	0.5	1260	100000
	EPS	90		25	0.036	1400	60
	Building Paper Felt	0.2		500	0.17	1500	9999
U = 0.388 W/m^{2}K	Sand blinding	150		2240	1.3	980	34
Uvalue = 0.400 W/m^{2}K	PP Non woven filter cloth	0.2		600	0.22	792	37500
Underground Garage Ceiling/ Courtyard	Terrazzo Tiles	50	562	2400	1.75	850	48
	Sand blinding	50		920	1.3	2240	34
	Crumb rubber mat	10		780	0.17	1360	2.3
	Bitumen dichtungsbahn	7.8		1100	0.23	1260	102000
	PE	1.6		980	0.5	1260	100000
	Reinforced concrete slab, 2% steel	150		2400	2.5	1000	130
	Air Layer	130		1.2	0.813	1000	1
U = 0.241 W/m^{2}K	Mineral wool	150		18	0.038	1030	1
Uvalue = 0.400 W/m^{2}K	Plasterboard	12.5		700	0.21	1000	10
Internal Floor/Internal Ceiling	Ceramic tiles	10	323	740	0.16	1600	200
	Cement Screed	50		2000	1.6	1000	15
	Reinforced concrete slab	150		2400	2.5	1000	130
	Air Layer	50		1.2	0.813	1000	1
U = 0.238 W/m^{2}K	Mineral wool	50		18	0.038	1030	1
N/A	Plasterboard	12.5		700	0.21	1000	10
Partition wall (between apartments)	Lime-Cement Plaster	15	195	1600	0.83	1000	10
	Accoustic insulation	20		11	0.033	1450	30
	Brick	125		850	0.314	1000	8
U = 0.194 W/m^{2}K	Accoustic insulation	20		11	0.033	1450	30
Uvalue = 0.900 W/m^{2}K	Lime-Cement Plaster	15		1600	0.83	1000	10
Apartment Wall to unheated space	Lime-Cement Plaster	15	225	1600	0.83	1000	10
	Concrete	100		1800	0.85	1000	50
	EPS W 20	70		20	0.038	1450	40
U = 0.525 W/m^{2}K	Concrete	25		1800	0.85	1000	50
Uvalue = 0.600 W/m^{2}K	Lime-Cement Plaster	15		1600	0.83	1000	10
Wall uninsulated	Lime-Cement Plaster	15	150	1600	0.83	1000	10
	Brick	120		800	0.34	1000	8
	Lime-Cement Plaster	15		1600	0.83	1000	10
Roof	Metal roof		382				
	PE Tyvek	0.6		325	0.42	1500	66
	Plywood Sheathing	16		500	0.13	1600	50
	Mineral wool in timber frame	40		18	0.045	1030	1
	Mineral wool in timber frame	120		18	0.038	1030	1
	Mineral wool in timber frame	40		18	0.038	1030	1
U = 0.194 W/m^{2}K	Reinforced concrete slab, 2% steel	150		2400	2.5	1000	130
Uvalue = 0.200 W/m^{2}K	Lime-Cement Plaster	15		1600	0.83	1000	10
Roof_flat	Sand blinding	50	452				
	Bitumen dichtungsbahn	7.8		1100	0.23	1260	102000
	XPS	30		33	0.033	1380	100
	PE	1.6		980	0.5	1260	100000
	Reinforced concrete slab, 2% steel	150		2400	2.5	1000	130
	Air Layer	50		1.2	0.813	1000	1
U = 0.191 W/m^{2}K	Mineral wool	150		18	0.038	1030	1
Uvalue = 0.200 W/m^{2}K	Plasterboard	12.5		700	0.21	1000	10

Vehicle access door	Aluminium foil	0.5	15	2800	160	880	100000
U = 2.220 W/m²K	EPS	13.5		10	0.04	1450	60
Uvalue = 2.500 W/m²K	Aluminium foil	0.5		2800	160	880	100000

Window	Triple glazing, Ar, low-e, 4-12-4-12-4	*Ug = 0.900 W/m²K*
Uw = 1.300 W/m²K	Softwood frame	*Uf = 1.510 W/m²K*
Uvalue = 1.400 W/m²K	Linear thermal transmittance coef.	*PSI = 0.050 W/mK*
Entrance Door	Double glazing, Ar, low-e, 4-12-4	*Ug = 1.500 W/m²K*
Ud = 1.600 W/m²K	Softwood frame	*Uf = 1.510 W/m²K*
Uvalue = 1.700 W/m²K	Linear thermal transmittance coef.	*PSI = 0.050 W/mK*

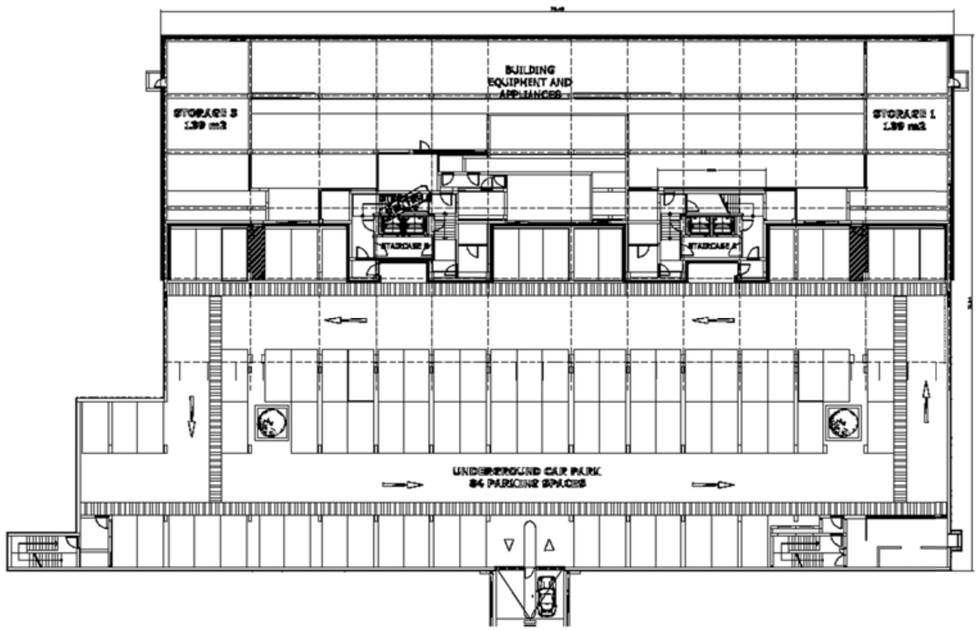

Figure A8 Office Basement

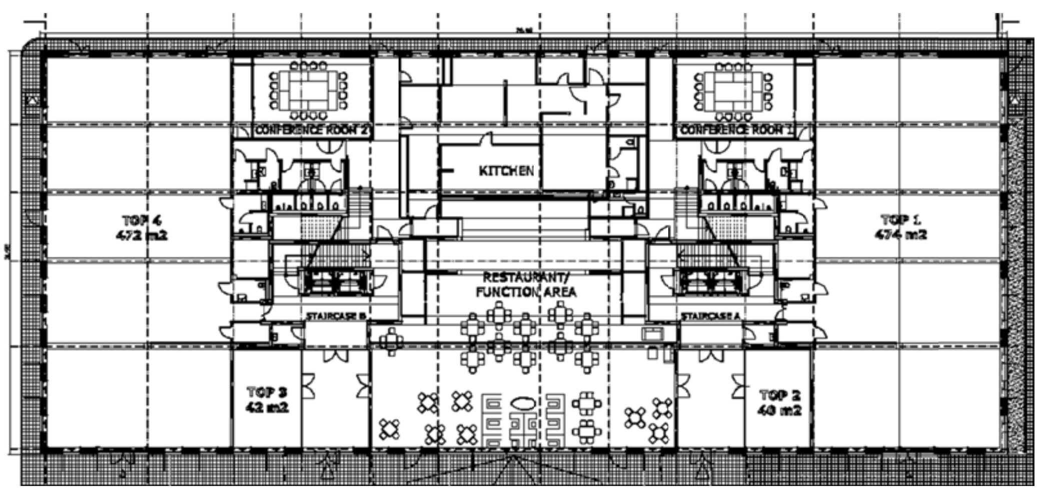

Figure A9 Office Ground Floor

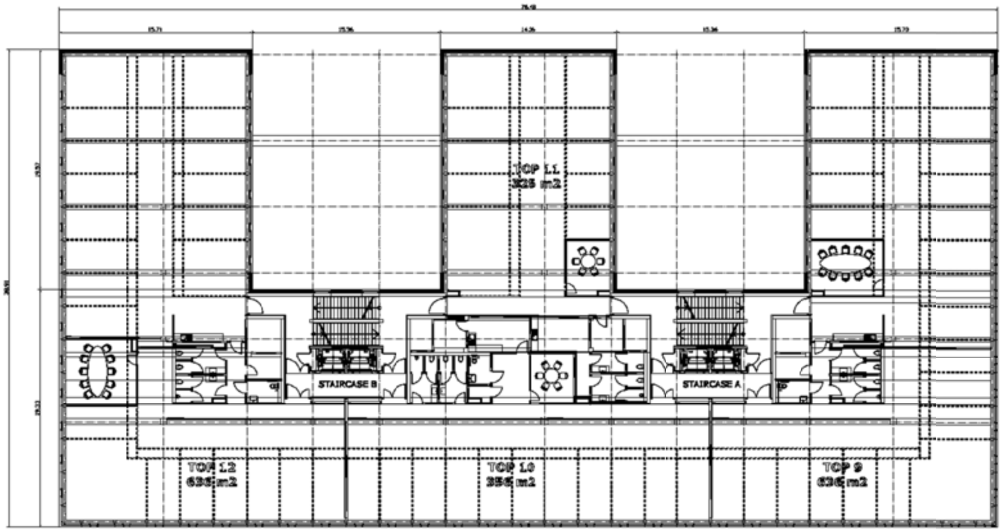

Figure A10 Office Level 2 to 5

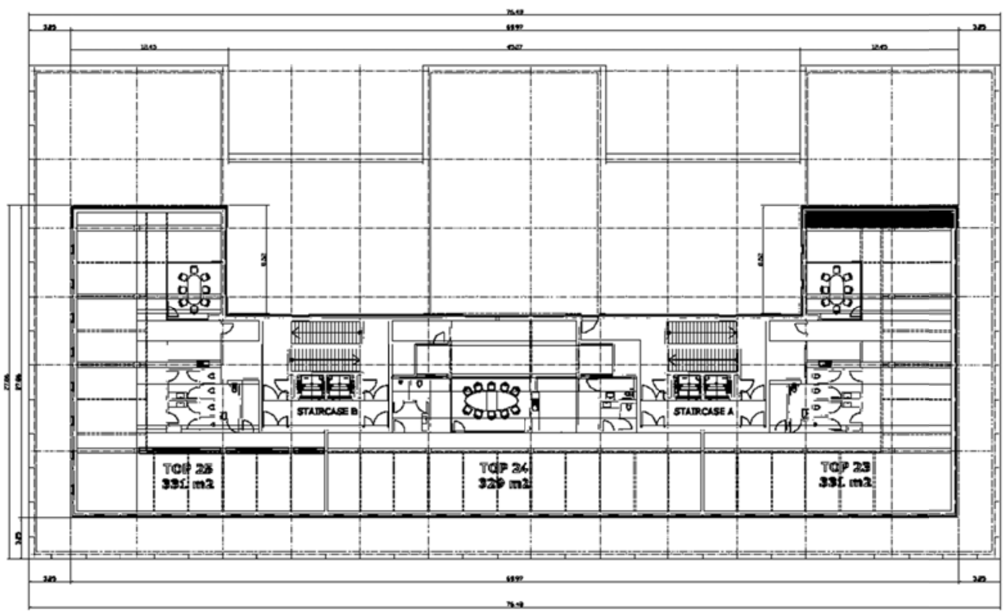

Figure A11 Office Top Floor