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Adaptation to Climate Change and Thermal Comfort

Investigating Adaptation and Mitigation Strategies for Kerman, Iran, Based on Traditional Iranian Urbanism and the German Experiences in the Ruhr

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By

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Chapter 1: Introduction

1.1. Background and context to this study

Climate change and its implications have been widely discussed in the academic society during the past decades. There are strong scientific evidences that prove the existence of changing trends in global climate. Changes in frequency, time and magnitude of climatic events are observed. In the context of Iran, the majority of recent research has been focusing on the meteorological aspects and the influences of climate change on agriculture. Therefore, a research on the effects of climate alterations on cities was essential.

Moreover, preliminary studies showed that there is an absolute absence of adaptation programs in the face of a changing climate. However, there have been local studies on the mitigation of climate change, performed to be presented to the IPCC, but these studies cover all the country at one level and do not focus on one climatic region or city in particular. Here as well, the prime objective of these studies has been the prevention of the negative impacts on the agricultural industry and rural areas. The necessity of a comprehensive adaptation and mitigation program was definitive. This research aims to contribute to this adaptation and mitigation program, in urban areas, specifically in Iranian cities with hot and dry climate.

It was essential to consider the rich heritage of Iranian urbanism in developing new programs for Iran. Climate related practices and policies of vernacular Iranian urbanism had to be investigated in detail to identify the key determinants of climate regulating mechanisms. While in traditional urbanism a great deal of attention was spent on passive climate regulation, and to achieve the most of the environment, during the past 50 years and with the introduction of Iranian modern architecture and urbanism, a national style of town planning has been common. The same issue is true in the architectural design of buildings. A major shortcoming of such a national style is the negligence towards local climates, especially in a country like Iran, which enjoys a broad range of different climates at the same time. Therefore, new urban codes and regulations that consider local issues, both climatic and socio-cultural, were essential.

Moreover, it was necessary to search for successful examples of adaptation and mitigation activities with similar contexts in other countries of the region. This could enable the decision makers to learn from mistakes and successes of similar experiences.

However, the study of successful cases should not be limited to countries with similar contexts. The research had to be more progressive, and consider countries with massive discrepancies in contexts, which in turn might uncover fresh ideas and concepts of adaptation that are also applicable to the Iranian case.

Germany, as a global leader in adaptation programs and as the physical location where this research is performed, was selected as a reference case. In particular, the Ruhr area received much attention, since it is undergoing massive structural and demographic transformations. There are already adaptation and mitigation plans available for this region, which create a platform for further investigation.

On the other hand, a framework had to be developed to facilitate the comparison of various adaptation strategies. To do this, first, relevant adaptation strategies had to be extracted from both Iranian and German cases to establish a toolbox of possible approaches in face of climate change. Then these strategies had to be categorized and classified, so that proper applicability study could be devised for each group.

Since these strategies were mostly too broad to be covered in a single research, much delimitation had to be performed. Eventually two main groups of strategies emerged: One that focused on the thermal comfort situation of pedestrians and the second group that was dedicated to energy. Naturally, these two groups constitute the pillars of this research.

In the field of urban climate, a massive amount of research has been performed. These studies cover human thermal comfort in many climates around the world, but do not present any specific connection between climate change and thermal comfort. Moreover, there is a very limited body of research available on the current urban climate of Iran and its future fate. Therefore, there was a missing link between international and local research that had to be found.

1.2. Aims of this research

In general, this research seeks to create a repository of adaptation and mitigation strategies, out of Iranian traditional urbanism and also adaptation activities performed in the Ruhr area. Furthermore, it seeks to explore the applicability of such strategies to the Iranian contemporary cities, particularly with hot and dry climate.

The outcome of this research is a set of suggestions to be incorporated into the Iranian urban design codes, both on local and regional scales that will facilitate a climate conscious urban development based on scientific facts and evidences. This research targets cities around the Iranian central desert.

1.3. Structure of the thesis

This dissertation consists of ten chapters and two appendices. The current chapter (Introduction) presents a brief background to the research and demonstrates the gaps in knowledge that will be bridged by this study.

The second Chapter (Theory) sums up the literature review conducted in this research and creates a theoretical basis for the analysis and discussion. Based on this theoretical background, the third chapter identifies research problems, research questions and goals. The delimitations involved in this research and other scopes are also discussed in this chapter.

The forth chapter describes the tools and methods used in this research. The methodology is explained and then some softwares that were involved are introduced. Moreover, the data sources are introduced and the obstacles faced in the course of this research are discussed.

The fifth chapter is dedicated to introduction of case studies of this dissertation. It consists of two parts. The first part provides a brief insight on Kerman, in terms of geography, predicted future climate and current urban design codes and trends. The second part introduces the Ruhr area in Germany. A brief history of this region is narrated and its unique features as a previously industrial polycentric agglomeration are discussed. This chapter intends to familiarize the reader with the contexts that are subject to further analysis in this research.

The next four chapters are dedicated to the analyses performed in this research. The first one (Chapter 6) of is the analysis of Iranian traditional architecture and urbanism. The second one (Chapter 7) analyzes the German adaptation and mitigation activities that were presented in two separate projects. These two chapters are the basis of the next two chapters. The results of these analyses on Iranian and German adaptation strategies constitute the input data of further analyses in other chapters. The third section in this series (Chapter 8) is on microclimate simulations. In this part, some adaptation strategies that were extracted before are put into test to examine their influence on outdoor thermal comfort. The next chapter (Chapter 9) is about energy conservation and production of renewable energies. In this section, the potential to produce energy from renewable sources in Kerman is discussed and then simple financial analyses investigate the feasibility of such change towards renewable energies.

It all comes to an end in chapter ten, which discusses the results of the previous analyses and sets forth conclusions based on these results. Furthermore, recommendations are introduced in form of urban design guidelines that can be incorporated into official regulations for urban development in order to promote a climate conscious urban growth.

The first appendix that accompanies this research gathers a list of sample values for the metabolic rate M in relation to a $1m^2$ surface area (A_{Du} surface area of the human body) for different activities. The second appendix demonstrates different physical characteristics of construction materials.

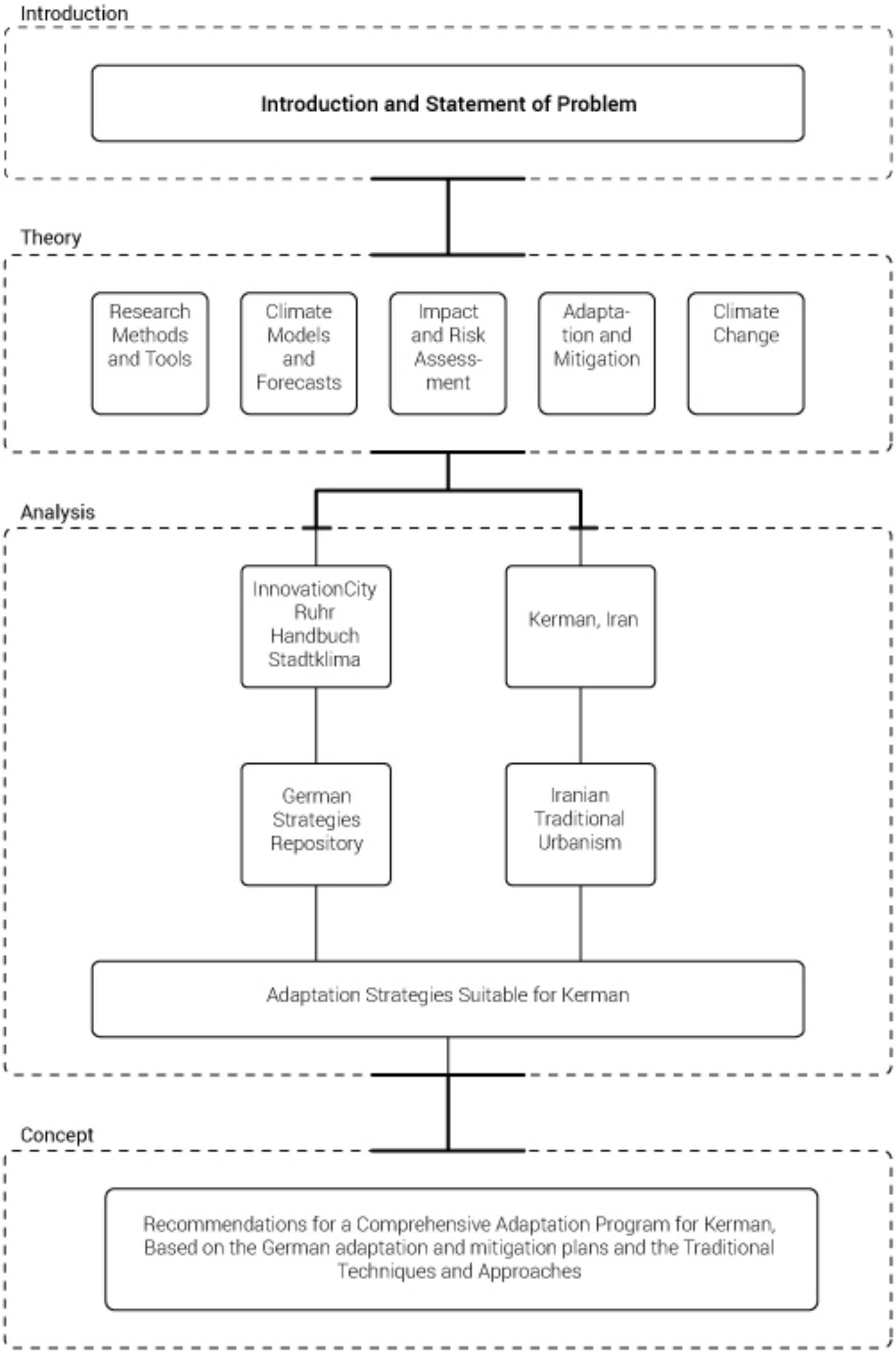

Figure 1: Research Roadmap

Chapter 2: Theoretical Background

This chapter seeks to establish a solid theoretical background, upon which the research questions are explained and investigated. Topics on climate change and its implications on cities and human livelihood are discussed.

2.1. Climate Change and its impacts

Although the climate change has attracted much attention in the recent years, it is not a new agenda in the academic world. The possibility that the climate could be changing was first noticed as far back as the 1960s. Since the 1950s, physical measurements of global CO_2 emissions have been performed. According to the records, there is an 18% increase in the mean annual concentration, from 316 parts per million by volume (ppmv) of dry air in 1959 to 373 ppmv in 2002 and 389 in 2009 (Figure 2). The 1997-98 increase in the annual growth rate of 2.87 ppmv was the largest single yearly jump since the Mauna Loa record began in 1958 (Roaf, Crichton and Nicol 2009).

First large scale modeling study of global environmental conditions that was prepared as input to the 1972 United Nations Conference on the Human Environment noted the possibility of "*inadvertent climate modification*".

By the mid-1980s, with clear evidence of increasing temperatures and the frequency and intensity of extreme weather events, the scientific simulated predictions on the warming climate began to demonstrate a close approximation to what was actually happening in the measured record.

In 1988, the UN Environment Program and the World Meteorological Organization established the Intergovernmental Panel on Climate Change (IPCC), consisting of hundreds of leading scientists and experts on global warming. The Panel was asked to assess the state of scientific knowledge concerning climate change, evaluate its potential environmental and socio-economic impacts, and formulate realistic strategies to deal with the problem.

On 11 December 1997, at the conclusion of COP-3 in Kyoto, Japan, more than 150 nations adopted the Kyoto Protocol. By this unprecedented treaty, the industrialized nations committed to make reductions in emissions of six greenhouse gases:

- Carbon dioxide.
- Methane
- Nitrous oxide
- Hydro-fluorocarbons (HFCs)
- Per-fluorocarbons (PFCs)
- Sulfur hexafluoride (SF_6)

The called-for reductions varied from country to country, but would cut emissions by an average of about 5% below 1990 levels by the period 2008 – 2012.

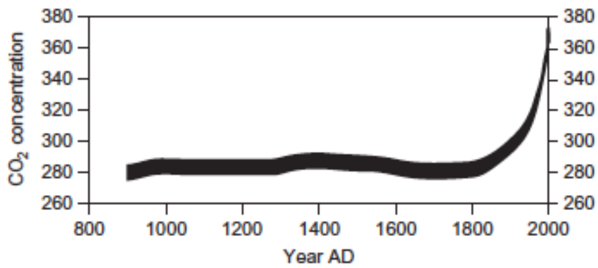

Figure 2: Increasing historic concentrations (parts per million) of CO_2 in the global atmosphere. The line thickness indicates uncertainty in the concentrations. (Source: IPCC from (Roaf, Crichton and Nicol 2009))

According to the latest report of the IPCC, Each of the last three decades has been successively warmer at the Earth's surface, than any preceding decade since 1850. In the Northern Hemisphere, 1983–2012 was likely the warmest 30-year period of the last 1400 years. The atmospheric concentrations of carbon dioxide (CO_2), methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. CO_2 concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification (Working Group I of the IPCC 2013).

More than 90% of the energy accumulated between 1971 and 2010, led to ocean warming, which dominates the increase in energy stored in the climate system.

There is a high confidence that the rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia. Over the period 1901–2010, global mean sea level rose by 0.19 [0.17 to 0.21] m. Global mean sea level will continue to rise during the 21st century and global glacier volume will further decrease. Moreover, the contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions. Sea levels will rise almost everywhere and many islands around the world will disappear as sea levels rise. Also, saltwater intrusion affects drinking water and food production.

According to the International Red Cross and Red Crescent, the intensity and frequency of disasters has increased and climate change will only make this worse. During 1994-1998 an average of 428 disasters were reported per year, however the same figure for the period of 1999-2003 has jumped to 707, mainly in the developing countries with a devastating increase of 142 percent (UN-HABITAT 2006, 136).

The main cause of global warming is the accumulation of greenhouse gases in the atmosphere. Greenhouse gases are building up in the upper atmosphere to form an increasingly dense layer that allows solar radiation into the Earth's atmosphere, but as this layer gets denser, it prevents more and more heat from radiating back into space, so warming the lower atmosphere and changing our climate (Roaf, Crichton and Nicol 2009).

Hansen et al. (2008) conclude that the current levels of CO_2 in the Atmosphere are too high:

"Continued growth of greenhouse gas emissions, for just another decade, practically eliminates the possibility of near-term return of atmospheric composition beneath the tipping level for catastrophic effects"

Changes in the climate are likely to emerge in four main ways: slow changes in mean climate conditions, increased inter-annual and seasonal variability, increased frequency of extreme events, and rapid climate changes causing catastrophic shifts in ecosystems (Tompkins and Adger 2004).

There is no doubt that the humans have had an influence on the climate system. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system. IPCC reports that it is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century (Working Group I of the IPCC 2013). Buildings are responsible for producing over half of all climate change emissions.

The impacts of a changing climate are already visible throughout the world; mass population migrations, increased regional conflicts (i.e. Darfur), massive water shortages and other human catastrophes (HM Treasury 2006).

Climate change has a negative impact on human and animal health as well. A study by scientists at the World Health Organization (WHO) in 2003 found that 160,000 people die every year from side-effects of global warming; increased rates of death resulting from a range of causes from malaria to malnutrition, and predicted that the number would double by 2020 (WHO 2003). In warmer climates, diseases spread by animals such as rats and insects are more common and issues such as the increasing scarcity of clean water with hotter, drier climates will also play a major part in increasing the number of deaths from illness and malnutrition. In addition, the combination of increasing temperature and more still water resulting from storms creates conditions conducive to epidemics, such as those of malaria. These conditions provide perfect breeding grounds for the insects and speed up their life cycle as a result of the warmer conditions. Furthermore, the climate warming causes a shift in regions where diseases can survive.

Human health is affected by climate change in three different ways:

- Direct impacts: death and injury from heat waves
- Indirect impacts: occurrence of health conditions intensified by weather conditions
- Migratory impacts: movement of sources of infection via various carriers with warming climates, e.g. malaria

Heat and cold stress, over exposure to sunlight, insect infestations, air pollution, water pollution, waste, noise and fires are all features that are exacerbated by the changing climate, which affect human health. They also have a negative impact on the biodiversity. Plant and animal species are being lost around the world with rising temperatures at a rate that has alarmed many scientists. Some of the most notable extinctions that are anticipated for the near future are those of the coral reefs, the Sumatran tiger, the Malaysian bear and the western gorilla. For some of these species there will no longer be anywhere suitable to live. Others will be unable to reach places where the climate is suitable to breed, feed or avoid thermal stress (Roaf, Crichton and Nicol 2009). The negative effects of climate change on human health are more visible in energy-inefficient homes and households with low incomes, a portion of the community that is more vulnerable because of *fuel poverty*.

Climate change is a key driver for mass violence as people begin to fight over increasingly scarce resources. Water shortages after droughts may lead to conflicts in societies.

Climate change impacts on communities may include: 1) the direct local effects of prevailing conditions and extreme events associated with issues such as sea-level rise, drought, heavy precipitation and flooding, etc. 2) the indirect effects of climate change in other places, such as storm disruption of remote energy supply-lines, drought in other food-exporting regions, and in-migration of environmental refugees (Sheppard, Pond and Campbell 2008).

Nearly all human societies and activities are sensitive to climate in some way or other because the place, where people live and the systems by which they generate a livelihood and wealth is influenced by the ambient climate.

Significance of climate change impacts can be judged by five numeraires: monetary loss, loss of life, biodiversity loss, distribution and equity, and quality of life, including factors such as coercion to migrate, conflict over resources, cultural diversity, and loss of cultural heritage sites (Schneider, Kuntz-Duriseti and Azar 2000).

2.1.1. Peak Oil

Peak oil is the point in time when the maximum rate of global petroleum extraction is reached, after which the rate of production enters terminal decline. The aggregate production rate from an oil field over time usually grows exponentially until the rate peaks and then declines—sometimes rapidly—until the field is depleted (Winfrey 2010). Peak oil is often confused with oil depletion; peak oil is the point of maximum production while depletion refers to a period of falling reserves and supply.

Some observers, such as petroleum industry experts Kenneth S. Deffeyes and Matthew Simmons, believe the high dependence of most modern industrial transport, agricultural, and industrial systems on the relatively low cost and high availability of oil will cause the post-peak production decline and possible severe increases in the price of oil to have negative implications for the global economy. According to the Export Land Model, oil exports drop much more quickly than production drops due to domestic consumption increases in exporting countries (The Oil Drum 2011). Supply shortfalls would cause extreme price inflation, unless demand is mitigated with planned conservation measures and use of alternatives (Gwyn 2004). This problem and the issue of oil security are so serious that even some intellectuals believe this was the reason of the US attack on Iraq (Engdahl 2004). Our development is highly dependent on cheap oil and for sure this cannot last forever.

2.1.2. Risk and Vulnerability

Risk is the potential for a damage to occur and it is composed of three elements (Roaf, Crichton and Nicol 2009):

1- Vulnerability: It is influenced by the design and fabric of the buildings, and habits, age, health and wealth
2- Exposure: The degree to which any population will be exposed to the worst extremes of climate change is related to their geographical location in relation to latitude, landmasses and the patterns of the changes experienced.
3- Hazard: Hazard is a term that is typically described in terms of the size of the risk and the frequency with which it is experienced.

If risk is measured by the area of an acute angled triangle, a reduction in any one side will reduce risk. Risk management then becomes a case of examining each of the three sides in turn to look for the most cost-effective solutions. In other words, adaptation to climate change or minimizing the risks of climate change impacts is achieved by minimizing vulnerability and exposure through adaptation measures. Adger and his colleagues (2005) describe the three cornerstones of adaptation as: reduce the sensitivity of the system to climate change, alter the exposure of the system to climate change, and increase the resilience of the system to cope with the changes.

There are several factors determining vulnerability or security of individuals and of societies, for example, likely responses of the resources on which individuals depend, availability of resources and the entitlement of individuals and groups to call on these resources. Moreover, the vulnerability of a system to climate change is determined by its exposure, by its physical setting and sensitivity, and by its ability and opportunity to adapt to change.

Based on the literature available in this field, Adger and his colleagues summarize the influential factors of vulnerability in their chapter in the Fourth Assessment Report: *"The vulnerability of a society is influenced by its development* *path, physical exposure, the distribution of resources, prior stress and social and governmental institutions."* (Adger, Agrawala, et al. 2007).

The impacts of the climate change are not evenly distributed; the people who will be exposed to the worst of the impacts are the ones least able to cope with the associated risks (Smit 2001). Cannon (1994) points out poverty and marginalization as key driving forces of vulnerability which constrain individuals in their coping and long-term adaptation. Moreover, as Kates argues, both vulnerability and adaptation processes to climate change are likely to reinforce unequal economic structures (Kates 2000), but inevitably it is the marginalized who suffer the impacts of changing environmental conditions (Ribot, Magalhaes and Panagides 1996). Groups marginalized within societies, including older people and women, are often also excluded from decision-making structures (Tompkins and Adger 2004). Increases in ecosystem resilience can be achieved through the reduction of social vulnerability by extending and consolidating social networks, both locally and at national, regional, or international scales.

Climate is inherently variable for natural reasons; therefore human societies have always and everywhere had to develop coping strategies against unwelcome variations in climate or weather extremes. Adger and his colleagues argue that since some of these coping strategies are more technologically dependent, better resourced, or more robust or resilient than others, therefore populations today are differentially vulnerable to existing variations in climate and weather based on structural factors (Adger, Huq, et al. 2003).

2.1.3. Adaptation

Adaptation to climate change is defined as *"the adjustment of a system to moderate the impacts of climate change, to take advantages of new opportunities or to cope with the consequences"* (Adger, Huq, et al. 2003). Adaptation activities are undertaken by a range of public and private actors through policies, investments in infrastructure and technologies, and behavioral changes (Adger, Agrawala, et al. 2007). Adaptation is not about returning to some prior state, because all social and natural systems evolve and, in some senses, co-evolve with each other over time (Tompkins and Adger 2004).

These activities are generally classified into two main groups: those that reduce dependence on vulnerable systems –introducing drought resistant crop varieties - and those that decrease the sensitivity –e.g. through strengthening existing infrastructures, making them less likely to be damaged by unusual events.

Adaptation activities vary according to the geographical scales and social agents that are involved (Adger, Huq, et al. 2003). Some adaptations by individuals are undertaken in response to climate threats, often initiated by individual extreme events (Ribot, Magalhaes and Panagides 1996). Other adaptation is undertaken by governments on behalf of society, sometimes in anticipation of change, but, again, often in response to individual events (Adger, Huq, et al. 2003).

These practices can be differentiated along several dimensions: by spatial scale (local, regional, national); by sector (water resources, agriculture, etc.); by type of action (physical, technological, etc.); by actors; by climatic zones; by development level of the system in which they are implemented and by some combination of these categories (Adger, Agrawala, et al. 2007).

We know enough about future climates to be able to modify our designs today to accommodate them. Adaptation to climate change occurs through adjustments to reduce vulnerability or enhance resilience in response to observed or expected changes in climate and related extreme weather events. Adaptation takes place in physical, ecological and human systems. It involves changes in social and environmental processes, perceptions of climate risk, practices and functions to reduce potential damages or to realize new opportunities. However, the diversity of impacts of climate change means that the most appropriate adaptation responses will often be on multiple levels (Tompkins and Adger 2004).

Adaptations include *anticipatory* and *reactive* actions, private and public initiatives, and can relate to projected changes in temperature and current climate variations and extremes that may be altered with climate change. Much of this adaptation is reactive, in the sense that it is triggered by past or current events, but it is also anticipatory in the sense that it is based on some assessment of conditions in the future.

Adaptation activities tend to be on-going processes, reflecting many factors or stresses, rather than discrete measures to address climate change specifically (Adger, Agrawala, et al. 2007). Adaptation can be motivated by many factors, including the protection of economic wellbeing or improvement of safety. It can be manifested in countless ways: through market exchanges, through extension of social networks, or through actions of individuals and organizations.

Furthermore, from a temporal perspective, adaptation to climate change can be viewed at three levels, including responses to: current variability (also reflects learning from past adaptations to historical climates); observed medium and long-term trends in climate; and anticipatory planning in response to model-based scenarios of long-term climate change (Adger, Agrawala, et al. 2007).

Individuals and communities are presently responding to climate change in the same way that they have dealt with climate variability throughout history (Adger and Brooks 2003). Innovation, which refers to the development of new strategies or technologies, or the revival of old ones in response to new conditions, is an important aspect of adaptation, particularly under uncertain future climate conditions (Bass 2005).

There is an important role for public policy in facilitating adaptation to climate change, which includes reducing vulnerability of people and infrastructure, providing information on risks for private and public investments and decision-making, and protecting public goods such as habitats, species and culturally important resources (Haddad, et al. 2003) (Callaway 2004).

Irrespective of motivation for adaptation, both purposeful and unintentional adaptation can generate short-term or long-term benefits. But they may also generate costs when wider issues or longer timeframes are considered.

With regards to adaptation costs and benefits in the energy sector, there is some literature on changes in energy expenditures for cooling and heating as a result of climate change. Although Tol (2002) estimated that for every degree increase in the average temperature, global benefits from reduced heating would be around US$120 billion, while global costs resulting from increased cooling would be around US$75 billion, most studies show that increased energy expenditure on cooling will more than offset any benefits from reduced heating (Adger, Agrawala, et al. 2007).

While an action may be successful in terms of one stated objective, it may inflict externalities at other spatial and temporal scales. Although an action may be effective for the adapting agent, it may produce side effects (negative externalities and spatial spillovers), potentially increasing impacts on others or reducing their capacity to adapt. Therefore, the definition of success depends on both the spatial and the temporal scale, and should not simply be assessed in terms of the stated objectives of individual adaptors. Adaptation to climate change, hence, can be evaluated through generic principles of policy appraisal seeking to promote equitable, effective, efficient and legitimate action harmonious with wider sustainability (Wreford, Moran and Adger 2010).

Effectiveness relates to the capacity of an adaptation action to achieve its expressed objectives. Effectiveness can either be evaluated through reducing impacts and exposure to them or in terms of reducing risk and avoiding danger and promoting security. The effectiveness of adaptation can sometimes be directly measured but more often it is more elusive.

Adapting to climate change involves costs, but should also lead to significant benefits. An economically efficient adaptation is not just a simple comparison of quantified costs and benefits. The timing of the adaptation action in relation to the climate change impact will also affect the perceived economic efficiency of an adaptation action.

According to Adger and his colleagues (2005), in case of adaptations, equity in outcome means identifying who gains and who loses from any impact or adaptation policy decision. They argue that this type of assessments, demonstrate that many present-day adaptation actions reinforce existing inequalities and do little to lessen underlying vulnerabilities.

In terms of equitable outcomes of climate change adaptations, the legitimacy of the decisions is influenced by the rules by which decisions are being made. They define *legitimacy* as the extent to which decisions are acceptable to participants and non-participants that are affected by those decisions. This legitimacy can be gained as well as compromised through the evolution of adaptation strategies. Since cultural expectations and interpretations define what is or is not legitimate, there are no universal rules for procedures that guarantee the legitimacy of policy responses. Social acceptance of any response strategy to environmental change of any form is also a critical factor. Response strategies themselves need to be flexible enough to be able to adjust to ongoing environmental and social change (Tompkins and Adger 2004).

Climate change planning by governments at present tends to concentrate on providing public goods such as scenario information, risk assessments in the public domain and public awareness campaigns (Callaway 2004).

Currently, there is an overreliance on the provision of mechanical systems to alleviate the more extreme climate conditions. These can add to the problem of climate change through the excessive use of fossil fuels energy. Adaptation to climate change needs the use of tried and tested techniques as well as the incorporation of modern technological approaches. In the past, countries have been assumed to take a path of increasing technological sophistication. However, in the response to climate change, it may be necessary to relearn skills that have fallen into disuse. As fuel prices increase, the ability to adapt to our surroundings is likely to be one of those skills.

As climate change begins to take hold, designers will have to look very closely at the available heat and cold in and around a site, and learn how to manage and move the resource from where it exists to where it is needed and how to protect inhabitants from it when it provides no benefit (Roaf, Crichton and Nicol 2009).

It is argued that, there were many ways in which buildings could be used and adapted to enable people to colonize the planet. For example (Roaf, Crichton and Nicol 2009):

- Choose a different climate for a different season, by migrating between summer and winter lands in transhumant or nomadic migrations.
- Change the form and/or materials of the building to provide a range of indoor climates that keep out or in the heat or cold as is needed over the year.
- Choose a different part of a building or space for use at a particular time of day or season on planned intramural migrations around one building.
- Import heat or cold into the building in the form of firewood, coal (where available), ice, sun or warm or cool air.
- Evolve the buildings and lifestyles to accommodate climate change.

Callaway argues that the benefits of both mitigation and adaptation are in nature local (Callaway 2004). He believes that while mitigation and adaptation reduce climate change in qualitatively different ways –mitigation by reversing changes in local climates and adaptation by adjusting to the local impacts of climate change- the benefits of both activities occur at the local level, as do the costs. He talks about the degree of "substitutability" between emissions reductions and adaptation in reducing local damages and suggest this factor as a tool for translating local marginal adaptation benefits into their local emissions reduction benefit equivalent. However, it is definitely clear that mitigation and adaptation are far from perfect substitute, since many of the local climate change damages that can (perhaps) be reduced by mitigation –for example many types of damages to unmanaged ecosystems- cannot be avoided by adaptation (Callaway 2004).

2.1.4. Mitigation

Climate change mitigation is a set of actions that are intended to limit the magnitude and/or rate of long-term climate change. Climate change mitigation generally involves reductions in human anthropogenic emissions of greenhouse gases. Mitigation may also be achieved by increasing the capacity of carbon sinks, e.g., through reforestation (IPCC AR4 WG3 2007).

Examples of mitigation include switching to low-carbon energy sources, such as renewable and nuclear energy, and expanding forests and other "*sinks*" to remove greater amounts of carbon dioxide from the atmosphere. Energy efficiency also plays a major role, for example, through improving the insulation of buildings.

In order to lower carbon emissions some sound practices have been suggested and implemented in some cities such as energy efficiency, the use of non-fossil fuels, controlled urban sprawl, improved public transport, waste recycling and water reclamation (UN-HABITAT 2006).

The most climate-damaging greenhouse gases are launched today in large cities. In order to curb climate change and its catastrophic consequences for man and the environment, it is necessary to rebuild our cities so that they consume less energy, emit less pollutant and deal with the nature responsibly. Because the cities - at least in case of Kerman - are in large part already built and only grow slowly, it is not enough to make only the newly added buildings and neighborhoods climate friendly. One must also try to include as many existing residential and commercial buildings, industrial buildings and the existing city equipment (i.e. power plants, power grids, water treatment plants, transportation systems, etc.) in the process of rebuilding to reduce their energy consumption and pollutant emissions (ICR 2012).

Sheppard et al (2008) argue that achieving a low carbon society is the only way of coping with the climate, especially considering the peak oil. In order to achieve these societies, they recommend four principles that need to be followed. Firstly, energy use should be reduced, through improved conservation and more building efficiency. Secondly, energy sources should be changed. Thirdly, transportation mode and fuel source should be changed. And lastly, re-localization should happen, especially in food production. A new definition of “compact, complete communities” is needed.

"Land use needs to be mixed to enable not only "live-work-play" activities, but also "produce" activities, that take into account carbon miles from imported food/materials versus local sources" (Sheppard, Pond and Campbell 2008).

2.1.5. Resilience and Adaptive Capacity

Resilience is often used to describe the capacity for positive adaptation despite adversity (Luthar and Cicchetti 2000). In the context of climate change, social resilience is the ability of groups or communities to adapt in the face of external social, political, or environmental stresses and disturbances (Adger 2000). To be resilient, societies must generally demonstrate the ability to (1) buffer disturbance, (2) self-organize, and (3) learn and adapt (Trosper 2002). Adaptive capacity, which is often used to refer to the set of preconditions that enables individuals or groups to respond to climate change (Olsson and Folke 2001), is a synonym for many characteristics of resilience.

Recovery from disaster impacts does not necessarily build resilience. Post disaster recovery frequently reinforces vulnerabilities and excludes sections of society in a way that undermines resilience (Pelling 2003).

Tompkins and Adger (2004) suggest that there is an incompatibility of current government structures with those suggested as necessary for promoting social and ecological resilience.

They propose that adaptive management processes, informed by iterative learning about the ecosystem and earlier management successes and failures, increase present-day resilience, which can in turn increase the ability to respond to the threats of long-term climate change (Tompkins and Adger 2004).

Adaptation involves both building adaptive capacity thereby increasing the ability of individuals and communities to adapt to changes, and implementing adaptation decisions, i.e. transforming that capacity into action (Adger, Arnell and Tompkins 2005).

In case of climate change, Adaptive capacity has been defined as the "*ability or potential of a system to respond successfully to climate variability and change, and includes adjustments in both behavior and resources and technologies*" (Adger, Agrawala, et al. 2007).

Adaptation capacity is influenced not only by the economic development and technology, but also by social factors such as human capital and governance structures (several studies, reported in (Adger, Agrawala, et al. 2007)). Moreover, high income per capita is considered neither a necessary nor a sufficient indicator of the capacity to adapt to climate change (Moss, Brenkert and Malone 2001). Human and social capitals are key determinants of adaptive capacity at all scales, and they are as important as levels of income and technological capacity. Self-efficacy and a sense of community have been identified as good predictors of community resilience and increased community capacity to respond to sudden changes (Paton, Millar and Johnston 2001).

Climate change negotiators, practitioners, and decision makers use national-level indicators of vulnerability and adaptive capacity in determining policies and allocating priorities for funding and interventions. However, these national indicators fail to capture many of the processes and contextual factors that influence adaptive capacity, and thus provide little insight on adaptive capacity at the level where most adaptations will take place (Eriksen and Kelly 2007). Community organization is an important factor in adaptive strategies to build resilience in communities (Robledo, Fischler and Patino 2004). Furthermore, Community engagement may offer a means of reducing vulnerability to the natural hazards associated with climate change (Abramovitz, et al. 2001).

Since multiple processes of change interact to influence vulnerability and shape outcomes from climate change, adaptive capacity is highly differentiated within countries (summarized in (Adger, Agrawala, et al. 2007)).

On the other hand, adaptive capacity can also vary over time and is affected by multiple processes of change. Adger et al. (2007) argue that the distribution of adaptive capacity within and across societies represents a major challenge for development and a major constraint to the effectiveness of any adaptation strategy. There are rarely simple cause-effect relationships between climate change risks and the capacity to adapt. Some adaptations that address changing economic and social conditions may increase vulnerability to climate change, just as adaptations to climate change may increase vulnerability to other changes.

The importance of social learning, specifically in relation to the acceptance of strategies that build social and ecological resilience is well demonstrated in the literature. Societies and communities dependent on natural resources need to enhance their capacity to adapt to the impacts of future climate change, particularly when such impacts could lie outside their experienced coping range.

Community-based management enhances adaptive capacity in two ways: by building networks that are important for coping with extreme events and by retaining the resilience of the underpinning resources and ecological systems (Tompkins and Adger 2004). The functioning of social networks and response capacity are closely linked: much adaptation to climate change occurs through collective action to mediate collective risk (Adger 2003).

In the area of responding to climate change, clearly the nature of the relationships between resource users at the community level, their access to new technology, and their willingness to change will determine their immediate response to climate change risks (Tompkins and Adger 2004).

Making decisions about what to do about climate change is complicated by uncertainties related to the size and distribution of the possible impacts, and consequently to the risks attached to making maladaptive responses (Tompkins and Adger 2004).

2.1.6. Mainstreaming

In the climate change context, the term *mainstreaming* has been used to refer to integration of climate change vulnerabilities or adaptation into some aspect of related government policy such as water management, disaster preparedness and emergency planning or land-use planning (Agrawala 2005).

Actions that promote adaptation include integration of climate information into environmental data sets, vulnerability or hazard assessments, broad development strategies, macro policies, sector policies, institutional or organizational structures, or in development project design and implantation (Huq, et al. 2003).

By implementing mainstreaming initiatives, it is argued that adaptation to climate change will become part of or will be consistent with other well-established programs, particularly sustainable development planning (Adger, Agrawala, et al. 2007).

The opportunities for implementing adaptation as part of government planning are dependent on effective, equitable and legitimate actions to overcome barriers and limits to adaptations (ADB 2005). Initial signals of impacts have been hypothesized to create the demand and political space for implementing adaptation, the so-called "*policy window hypothesis*".

The policy window hypothesis refers to the phenomenon whereby adaptation actions such as policy and regulatory changes are facilitated and occur directly in response to disasters, such as those associated with weather-related extreme events (Kingdon 1995). According to this hypothesis immediately following a disaster, the political climate may be conductive to legal, economic and social change which can begin to reduce structural vulnerabilities, for example, in such areas as mainstreaming gender issues, land reform, skills development, employment, housing and social solidarity. The assumptions behind the policy windows hypothesis are that:

- New awareness of risks after a disaster leads to broad consensus
- Development and humanitarian agencies are 'reminded' of disaster risks
- Enhanced political will and resources become available.

However, contrary evidence on policy windows suggests that, during the post-recovery phase, reconstruction requires weighing, prioritizing and sequencing of policy programming, and there is the pressure to quickly return to conditions prior to the event rather than incorporate longer-term development policies (Christopolos 2006). In addition, while institutions clearly matter, they are often rendered ineffective in the aftermath of a disaster. As shown in diverse contexts, such as ENSO-related impacts in Latin America, induced development below dams or levees in the U.S. and flooding in the United Kingdom, the end result is that short-term risk reduction can actually produce greater vulnerability to future events [summarized in (Adger, Agrawala, et al. 2007).

2.1.7. Limits and barriers to adaptation

There are significant barriers to implementing adaptation. These include both the inability of natural systems to adapt to the rate and magnitude of climate change, as well as technological, financial, cognitive and behavioral, and social and cultural constraints (Adger, Agrawala, et al. 2007).

The U.S. National Assessment (2001) maintains that adaptation will not necessarily make the aggregate impacts of climate change negligible or beneficial, nor can it be assumed that all available adaptation measures will actually be taken.

Further evidence from Europe and other parts of the globe suggest that high adaptive capacity may not automatically translate into successful adaptations to climate change (O'Brien, et al. 2006).

These limitations can be categorized into three main groups:

1- Technological limitations:

Existing or new technology is unlikely to be equally transferable to all contexts and to all groups or individuals, regardless of the extent of country-to-country technology transfers (Baer 2006).

2- Informational and cognitive barriers:

Uncertainty about future climate change combines with individual and social perception of risk, opinions and values to influence judgment and decision-making concerning climate change (Oppenheimer and Todorov 2006). Interpretations of danger and risk associated with climate change are context specific (Lorenzoni, Pidgeon and O'Connor 2005), and adaptation responses to climate change can be limited by human cognition (Grothmann and Patt 2005).

Four main perspectives on informational and cognitive constraints on individual responses (including adaptation) to climate change emerge from the literature:

a) Knowledge of climate change causes, impacts and possible solution does not necessarily lead to adaptation

b) Perceptions of climate change risks are differing:
While concern about one type of risk increases, apprehension about other risks decreases. Consequently, concerns about violent conflict, disease and hunger, terrorism, and other risks, in most cases, overshadow considerations about the impacts of climate change and adaptation. Individuals tend to prioritize the risks they face; focusing on those they consider to be the most significant to them at that particular point in time.
A lack of experience of climate-related events may inhibit adequate responses. For instance the capacity to adapt to familiar changes among resource-dependent societies in southern Africa is high, based on adaptations to previous changes (Thomas, et al. 2005).

c) Perceptions of vulnerability and adaptive capacity are important. Grothman and Patt (2005) found that action was determined by both perceived abilities to adapt and observable capacities to adapt. They concluded that a divergence between perceived and actual adaptive capacity is a real barrier to adaptive action.

d) Appealing to fear and guilt does not motivate appropriate adaptive behavior.

For behavior or policy change, an individual's awareness of an issue, knowledge, personal experience, and a sense of urgency of being personally affected, constitute necessary but insufficient conditions. Perceptions of risk, of vulnerability, motivation and capacity to adapt will also affect behavioral change. These perceptions vary among individuals and groups within populations.

3- Social and cultural barriers:

Thomas and Twyman (2005) analyzed natural-resource policies in southern Africa and showed that even so-called community based interventions to reduce vulnerability create excluded groups without access to decision-making. Most analyses of adaptation suggest that successful adaptations involve marginal changes to material circumstances rather than wholesale changes in location and development paths.

Information about the impacts of climate change on a detailed level is required by the authorities to enable them to devise fruitful adaptation activities. The exchange of information between the responsible actors is critical to this process. However, these communication needs are mostly neglected in planning processes. Rannow and his colleagues (Rannow, et al. 2010) report that this might be due to (a) the uncertainties intrinsic to the projection of climate change impacts, (b) the gap between scientific projections and their translation into management action, and (c) the dominant neglect of the social impacts of climate change in regional and local assessments.

Climate change messages are often associated with environmentalism and environmentalists, who have been perceived by many residents of resource-dependent communities as an oppositional political force, or even a fancy, luxurious trend. Societies change their environments, and thus alter their own vulnerability to climate fluctuations. Although many societies are highly adaptive to climate variability and change, vulnerability is dynamic and likely to change in response to multiple processes, including economic globalization (Leichenko and O'Brien 2002).

2.1.8. Four scenarios in Peak Oil

Newman, Beatley and Boyer (2009) point out four scenarios, which are possible to happen in case of peak oil and even severe climate change. The first one is gated community, where elite citizens will develop self-supportive urban villages within the cities. These communities will be highly fortified against other citizens who are living in poor conditions outside the walls. The second possible situation is the return to the rural system, where the cities will become large villages based on agriculture. The third scenario is the collapse of civilization and the forth, the resilient city. In his earlier work (Newman and Kenworthy 1999), Newman and his colleague propose a Future City, mainly based on the extension of transit network, limitation of urban sprawl and promotion of urban villages.

2.2. Urban Climate

2.2.1. Urbanization and Climate Change

Cities' spatial patterns, growth, and development will be impacted by the climate change. Today, more than half of the global population is already urban and the trend of migrating into urban areas is increasing. It is estimated that by 2030 at least 61 percent of the world's population will be living in cities. 95 percent of all the population growth will be absorbed by cities in developing countries, which will be home to almost 4 billion people (80 percent of the world's urban population).

"*What was once dispersed rural poverty is now concentrated in urban informal and squatter settlements*" (Prasad, et al. 2009)

More than half of the world's slum populations of 581 million are located in Asia (UN-HABITAT 2006, 12) and by 2015, 12 out of the largest 15 cities in the world will be in developing countries.

Concentration of population in urban areas has both negative and positive results. There will be more opportunities, as well as more vulnerability to natural hazards, civil strife, and climate change impacts.

Urbanization affects different aspects of climate, such as radiation and temperature, humidity, wind, precipitation, wind and air quality. A very well documented example of human induced climate change is performed by Oke (1994).

The buildings and structures in urban developments have influence on the absorption and reflection of solar radiation, the ability to store heat, winds and evapotranspiration (Johansson 2006). Human activities affect the climate too, such as air conditioning of the buildings, motor traffic and industrial production. Apart from the heat and moisture that these activities release, they also pollute the air, which affect incoming and outgoing radiation.

Airborne aerosols, which are partly a result of vehicles and industrial activities, diminish the incoming solar radiation and increase its diffusion. The reduction of global solar radiation in most cities is bellow 10%, but in highly polluted cities this may increase to more than 20% (T. Oke 1988) (Arnfield 2003). Oke (1987) identifies pollution as the cause of increased absorption of the outgoing long-wave radiation by the atmosphere. This absorbed radiation is re-emitted towards the ground.

All in all, it is obvious that the increasing rate of urbanization exacerbates the negative effects of climate change. However, this urbanization may also produce the potential to a climate friendly renewal or redevelopment of the urban fabrics.

2.2.2. Urban Heat Island

2.2.2.1. Definition and causes

The urban heat island (UHI) is a phenomenon in which the air temperatures in urbanized areas is elevated relative to surrounding rural areas (Corburn 2009). The UHI effect is assumed to warm urban areas 3.5 – 4.5 °C and is expected to increase by approximately 1 °C per decade (Voogt 2002).

The urban heat island is considered to be primarily a nocturnal phenomenon (Arnfield 2003), which means the temperature difference between an urban area and its rural surroundings is higher during nights. Johansson (2006) argues that this temporal difference leads to decreased diurnal temperature range in built up areas in comparison to rural areas.

Studies show that the magnitude of heat islands during nights has a direct relationship with the H/W [1] ratio of street canyons. Also using surface temperature simulations, it has been proven that the street geometry and the nocturnal heat island are linked (Oke, Johnson, et al. 1991), (Arnfield 1990), (Johansson 2006).

Since the urban surface materials have relatively high thermal capacity, they absorb solar energy during the day, store it in the urban fabric and release it back into environment at night. Therefore, if the difference in thermal admittance of urban areas is increased in comparison to its rural counterparts, the size of the heat island will also increase (Nakamura and Oke 1988). Increased emissivity from the sky and increased wind speed will decrease the size of the

[1] H/W ratio is the ratio between the height of the buildings (H) and the width of the adjacent street (W). This ratio is employed to demonstrate the openness of a street. In case that the height of the buildings on both sides are not equal, the average is considered.

urban heat island (T. Oke 1982), which means that during calm and cloudless nights the largest urban-rural temperature differences occur (Johansson 2006).

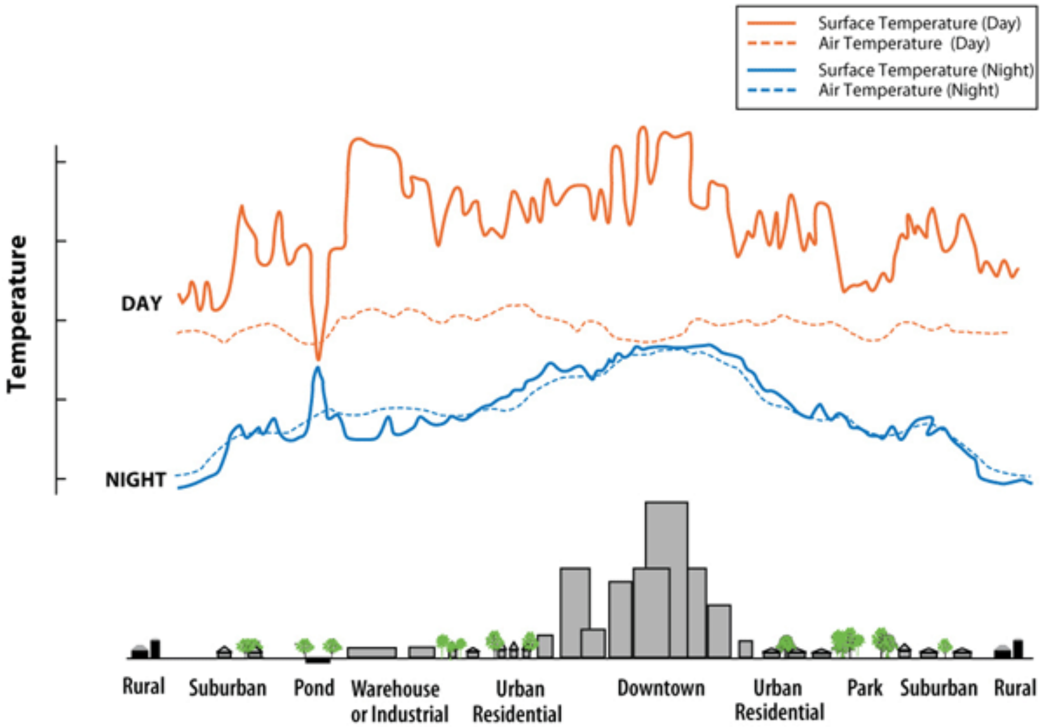

Figure 3: Various impacts of different land uses on diurnal and nocturnal temperature (NC State University 2013)

Apart from the daytime heat islands that are normally caused by anthropogenic heat, Oke (1982) identifies cool islands, attributed to the shade of buildings and vegetation.

There is a significant amount of literature available on the impact of green areas and vegetation on air temperature. It has been stated that larger parks are normally 1-2°C cooler than built-up areas (T. Oke 1989) but this difference in temperature can reach as much as 5°C (Upmanis, Eliasson and Lindqvist 1998). As the sky view factor (SVF)[2] is higher in these parks, therefore the ground is cooled more efficiently through net outgoing long-wave radiation. Another reason behind this reduced temperature is the low heat storage in surfaces compared to street canyons (Johansson 2006).

Due to the oasis factor[3] irrigated green areas tend to be considerably cooler than built-up areas (T. Oke 1989). The evaporation from vegetation and moist soil, in case there is excess water, takes energy from the air and cools it. Although for single trees and small clusters of trees the effect of evaporation on

[2] Sky view factor ranges from zero to one and is calculated as the amount of sky visible when viewed from the ground up

[3] This refers to the increase in evaporation rates when dry regions surround water bodies.

air temperature is marginal, but due to shading of the ground, air temperatures may be reduced (Johansson 2006).

Study performed by Shashua-Bar and Hoffman (2000) shows the effect of trees in urban streets. They found out that the air temperature in streets with tree lines on both sides are 2-4°C cooler. Also nocturnal cooling is reduced as the trees block the outgoing long-wave radiation from the canyon surfaces. They conclude that trees help create a more conservative climate with cooler days and warmer nights (Johansson 2006).

However, airborne particles and air pollutants tend to get trapped under large tree canopies at the pedestrian level. Therefore, in the design process of streets with vegetation, especially in streets with high motor vehicle traffic, this fact should be considered.

Generally speaking, differences in humidity in urban and rural areas are negligible. However Myer and his colleagues (2003) identified a phenomenon called "urban moisture excess" which claims that cities are slightly more humid by night and dryer by day than their rural surroundings. This fact enhances the heat island effect slightly, as the incoming long-wave radiation over cities increases compared to the surrounding rural areas (Johansson 2006) (Oke, Johnson, et al. 1991).

2.2.2.2. Impacts of UHI

This higher temperature will result in locally acute adverse human health, economic and environmental impacts (Corburn 2009). According to experts, exposure to excessive heat kills more people each year in the US than deaths from all other weather-related events combined (CDC 2006). These extreme heat events tend to impact disproportionately the urban poor, elderly, and infirm –all population that tend to lack the economic support systems necessary to avoid adverse health impacts associated with extreme heat (Klinenberg 2002).

Moreover, it is estimated that for each 1°C increase in the UHI intensity, the energy demand would increase 2 to 4% (Akbari, Pomerantz and Taha 2001). In the context of Los Angeles, Akbari and his colleagues estimate that 5-10% of the current energy demand of the city is consumed to cool buildings, just to compensate for the UHI increase since 1940 (about 0.5-3°C).

2.2.2.3. UHI Mitigation strategies

The literatures on UHI suggest three main mitigation strategies: Planting trees in open spaces or along streets; blanketing rooftops with vegetation (living roofs/ green roofs); and, increasing the reflectivity of built surfaces (Rosenzweig, Solecki and Slosberg 2006, Akbari, Davis and Dorsano 1992). Tree canopies shade built surfaces and also cool the air through evapotranspiration (Taha 1997). Green roofs can cool the roof surface of a building through evaporation from soil media and transpiration from plants, reducing air temperatures above roof, which then mix the adjacent air to cool the entire surrounding area (Davis, Martien and Sampson 1992). These roofs also result in reduced building energy demand in summer time by reducing the amount of solar energy that is conducted into a building and improve the quality of storm water runoff (Corburn 2009, 417). Furthermore, in cities with limited space for street-level planting, like New York, Green roofs could provide additional area for introducing cooling vegetation into the urban environment.

Surface lightening includes, but is not limited to, mixing lighter-colored aggregate into asphalt, typically on streets and rooftops. While urban areas typically have large areas available for surface lightening, light-colored surfaces are difficult to keep clean and may lose up to one-third of their reflectivity in a few years due to staining, weathering and soot deposition (Bretz and Pon 1994).

According to Corburn (2009), some land use data are known to alter temperature, including reflectivity of surfaces (albedo) and vegetation density. An albedo of 0.5 suggests that 50 per cent of incident solar radiation is reflected and surfaces with a higher albedo tend to be cooler than those with a lower albedo. However, as Rosenzweig and his colleagues noted in the NYCRHII final report (2006), "curbside planting, living roofs and light roofs and surfaces have comparable cooling effects" but that "light surfaces required an area many times greater than the area for street trees needed to achieve comparable cooling" rendering this intervention less cost-effective than street tree planting.

Some studies in hot dry cities show that the increase in H/W ratio will decrease the maximum daytime temperature (Ali-Toudert, Djenane, et al. 2005) and in some cases will increase the nocturnal temperature (Bourbia and Awbi 2004). Similarly, the effect of street orientation on air temperature has been studied in these cities as well. Pearlmutter and his colleagues (1999) found out that by day north-south oriented street was slightly cooler than east-west oriented street. However their study shows no difference in temperature by night. Bouria and Awbi (2004) also reported cooler daytime temperatures (1-2°C) in north-south oriented streets in comparison to east-west streets.

In conclusion, many studies based on field surveys on intra-urban temperature variations prove a significant influence by the urban geometry on air temperature. They also show that daytime maximum temperature tend to decrease with increasing H/W ratios, however this temperature is not affected by the street orientation to a significant extend.

2.3. Climate and comfort

The field of "human biometeorology" deals with the effects of weather conditions, climate and air quality on the human organism. Three specific areas of human biometeorology are particularly important in preventive planning (VDI 2008):

- Thermal factors: consist of elements that have a thermo-physiological effect on humans, such as air temperature, humidity, wind speed and so on
- Air quality factors: the solid, liquid and gaseous, natural and anthropogenic air pollutants affecting human health
- Actinic factors: visible and ultraviolet spectrum of solar radiation with a direct biological action beyond thermal comfort

Apart from these main factors there are other variables, which may have a pollutant influence on the human wellbeing, such as odor, noise and wind.

While indoor thermal comfort is well documented, the current knowledge on outdoor comfort is much more limited. Ali-Toudert and Mayer (2006) believe that the reason behind this lack of knowledge lies in the different ways urban climatologists and designers have dealt with the issue of understanding the relationship between buildings and urban climate. However, recently the collaboration on the topic of outdoor thermal comfort, between both disciplines has increased. This fact is observable in the recent literature and scientific forums.

Most of the investigations extend indoor comfort methods to outdoors by considering only air temperature, humidity and wind speed (Grundström, et al. 2003). In these investigations, the mean radiant temperature (T_{mrt}) is assumed to be equal to the air temperature (T_a). This approximation is not accurate at all and cannot reflect the outdoor actual situation. In fact, in sunny conditions, the discrepancy between T_{mrt} and T_a can be as high as 30°K. It is argued that even in shaded parts of a street canyon, due to the diffuse and reflected solar radiation components, air temperature can be of several degrees lower than the T_{mrt} (Mayer and Höppe, Thermal comfort of a man in different urban environments 1987). However, studies that focus on radiation fluxes confirm the advantage of shading towards a reduction of the radiant heat gained from a human body when compared to a person standing in a fully exposed environment.

Bio-meteorological investigations confirm that shading is an efficient strategy to mitigate heat stress. These studies show that outdoor thermal comfort depends strongly on the short and long-wave radiation fluxes from the entire surroundings of human beings.

In order to understand the human thermal comfort, first the human heat balance and the thermophysiological principles should be discussed. The human body has the capability to keep its core inner temperature constant within a narrow fluctuation band under varying conditions and irrespective of changing thermal ambient conditions (Hales 1984). A number of autonomous physical and chemical regulation mechanisms adapt heat loss and heat formation to the environmental conditions resulting from the combined effect of air temperature, air humidity, wind velocity and short wave and long wave radiation. Moreover, humans have the ability to assist their thermoregulations by adapting their behavior. For example, we can adapt to heat stress by moving into the shade or put on more cloths and expose ourselves to sunshine if we feel cold. Since the interindividual scatter spreads about two times as far as that of intraindividual values (VDI 2008), as the feeling of comfort fluctuates from day to day, it is difficult to distinguish an optimum thermal condition for all individuals. However, it is possible to achieve conditions of thermal comfort for a large section of the population. There are some factors that may limit the efficiency of these thermoregulatory mechanisms. For example, the body may not be able to reduce heat sufficiently because of obstruction of evaporation due to a lack of ventilation with a high concentration of water vapor in the air, or unsuitable clothing or unadapted activity. In this case, although the thermoregulation is working to a maximum, the body temperature rises, which may lead to serious health conditions, particularly of older people and those with a labile circulation. The same applies to heat loss as well. Even under less extreme deviations from conditions of comfort, the total population suffers considerably from adverse effects in wellbeing and performance.

In order to evaluate thermal climatic conditions, a description of the different fluxes in heat exchange between the body and the environment is necessary. Here, the heat balance equation for the body comes into play. According to the first law of thermodynamics, the quantities of energy taken in and given out must be identical in steady-state conditions in order to reach a balance of energy flows. Therefore, to maintain a thermal equilibrium, the heat formed by the metabolism in the human organism must be given off to the environment completely (Figure 4). However, external mechanical power should be taken into consideration as well.

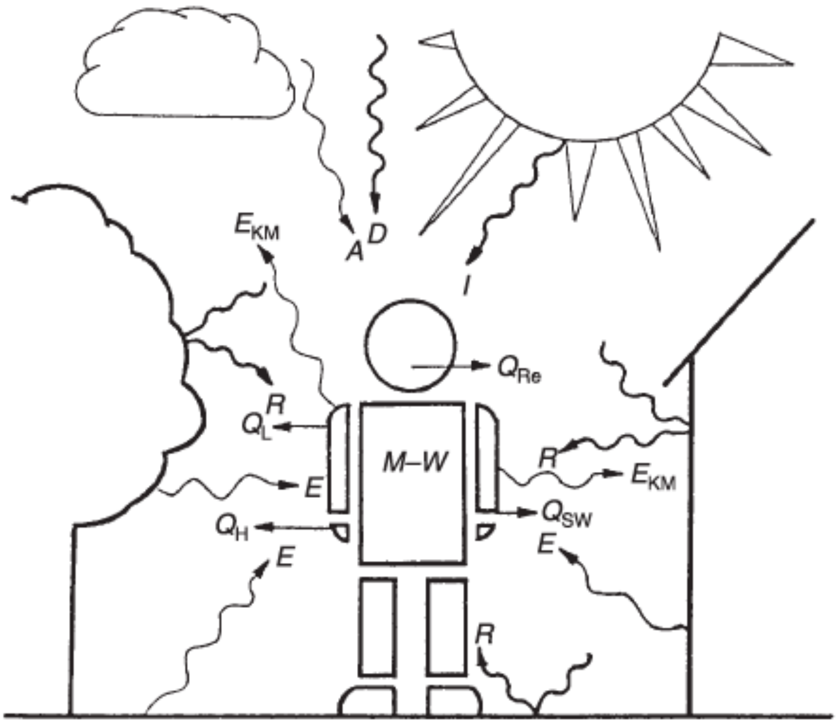

Figure 4: The components in the human heat balance (VDI 2008)

In other words, to reach the thermal balance the following conditions should be met according to Equation 1:

Equation 1

$$M + W + Q^* + Q_H + Q_L + Q_{SW} + Q_{Re} = 0$$

Components in the human heat balance:

M	Metabolic rate
W	Mechanical Power
Q_H	Turbulent flux of sensible heat
Q_{SW}	Turbulent flux of latent heat (Evaporation of sweat)
Q_L	Turbulent flux of latent heat (diffusion of water vapor)
Q_{RE}	Heat flux through respiration (sensible and latent)

Components of the radiation budget *Q^*:*

I	Direct solar radiation
D	Diffuse solar radiation
R	Reflected radiation, short wave
A	Atmospheric thermal radiation
E	Thermal radiation of surrounding surfaces
E_{KM}	Thermal radiation of the human body

In the mentioned formula, all the terms have the unit of power (W), and they have a plus sign if they result in an energy gain for the body and vice versa (VDI 2008). Sample values for the metabolic rate M in relation to a $1m^2$ surface area (A_{Du} surface area of the human body) for different activities can be found in Appendix I. Although the values listed in Appendix I can deviate up to ±25% depending on age, sex, fitness, practice and other individual differences, the metabolic rates given here are the basis for this research.

Urban design interventions can alter the heat balance by influencing the following meteorological parameters (VDI 2008):

- Radiation budget Q^* (direct and diffuse solar radiation, reflected radiation (short wave), atmospheric thermal radiation, thermal radiation of surrounding surfaces)
- Flux of sensible heat Q_H (Air temperature, wind velocity)
- Flux of latent heat through the evaporation of sweat Q_{SW} (wind velocity, air humidity).

The aforementioned meteorological variables depend on:

- Land use in developed and undeveloped areas
- Material and color of the exterior surfaces of buildings
- Material, type and color of road and ground coverings

Moreover, adapted behavior, i.e. choice of clothing, can influence the heat transition resistance between the surfaces of the skin and clothing, therefore causing significant changes to the conditions of heat output.

The gradient of a variable, the difference between the value at the surface of the human body and in the atmosphere, determine the intensity of the energy exchange. In case of turbulent fluxes of sensible and latent heat, the wind velocity also plays a role. At low wind velocities, small changes have relatively large effects on the heat balance, while an increase has far smaller effects. In other words, even slight improvements to the ventilation conditions in densely populated areas can lead to a great reduction in heat stress (VDI 2008).

The heat balance equation is the basis for the evaluation of thermal factors. Several indicators have been proposed for this evaluation, which will be discussed later.

In general, two conditions must be fulfilled in order to maintain thermal comfort. One is that the actual combination of skin temperature and the body's core temperature provide a sensation of thermal neutrality. Secondly, the heat produced by the metabolism should be equal to the amount of heat lost from the body, so that the energy balance of the body is fulfilled.

In this section, the impacts of several climatic features on the human thermal comfort are discussed.

2.3.1. Temperature and relative humidity

Sensation of comfort in cold conditions is linked to the heat balance of the human body, i.e. the heat loss due to conduction, convection, radiation and evaporation and the heat generated by metabolic processes, therefore temperature and relative humidity can both have significant impact on a person's comfort. The wind conditions are closely linked with the effects of temperature and humidity in convective and evaporative losses, and cannot be neglected. For example, in cooler regions, in order to meaningfully describe how cold the weather really feels like, the wind chill equivalent temperature is used, instead of simply giving air temperature. The equivalent temperature is obtained by calculating the temperature in standard wind (set at 1.8 m/s = 4mph) that would give the same rate of heat loss from exposed skin at 33°C as occurs in the actual wind and temperature conditions (Stathopoulos 2009).

Mostly, humidity has little direct effect on thermal comfort in cold conditions, while there may be indirect effects, such as changing the insulation factor of clothing. On the other hand, in hot conditions in order to maintain thermal comfort, the human body needs to increase heat losses through reducing clothing and sweating, which leads to heat loss due to the latent heat of evaporation. With the increase of the relative humidity the efficiency of evaporation is decreased, therefore it turns into a much more important factor in hot climates.

2.3.2. Solar Radiation

Needless to say that solar radiation conditions affect how humans experience the outdoor climates. Mainly three different variables should be considered: the angle of the sun, the amount of the sun light absorbed and reflected by buildings and the amount of radiation absorbed by clouds and other particles in the atmosphere.

The human body receives solar radiation in three different ways: directly, diffused through clouds and airborne water vapor, and lastly reflected from objects in the environment, e.g. buildings and ground. Mean radiant temperature[4] (MRT) is an indicator designed to measure the interactions of human body with its surrounding environment in terms of radiations. When MRT is higher than the temperature of the exposed skin (or that of the outer layer of clothing), there is a radiative heat gain (Johansson 2006).

2.3.3. Precipitation

Since people tend to stay indoors in case of heavy rain conditions, their wind and thermal comfort will usually be less critical compared with other microclimate factors. However, dampness of clothes as an effective issue on the thermal comfort should be considered.

2.3.4. Wind and air speed

With increasing air speed, the magnitude of convective and evaporative heat transfer coefficients increase, ergo both the convective heat loss and the evaporation of sweat will increase.

2.3.5. Mean radiant temperature

In extending the assessment of human comfort from indoors to outdoors, a critical issue is the need for a quantity that sums up all short-wave and long-wave radiation fluxes that are absorbed by a human body and affect its energy balance. This quantity is mean radiant temperature T_{mrt}. Regardless of the thermal comfort index used; T_{mrt} is the main variable in assessing daytime thermal sensation in outdoor environments. This quantity is calculated by the following formula (VDI 1998):

[4] This is defined as "the uniform temperature of an imaginary enclosure in which radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure" (ASHRAE 1997)

Equation 2

$$T_{mrt} = \left[\frac{1}{\sigma} \cdot \sum_{i=1}^{n} \left(E_i + a_k \cdot \frac{D_i}{\varepsilon_p} \right) \cdot F_i \right]^{0,25}$$

In this formula, the surrounding environment is divided into *n* isothermal surfaces[5]. For each of these surfaces, the variables of this formula are defined as follows (Ali-Toudert and Mayer 2006):

E_i: Long-wave radiation component

D_i : Diffuse and diffusely reflected short-wave radiation

F_i: The angle-weighting factor

I: Direct solar radiation impinging normal to the surface

f_p: The surface projection factor (a function of sun's position and the body posture)

α_k: The absorption coefficient of the irradiated body surface for short-wave radiation (≈0.7)

ε_p: The emissivity of the human body (≈0.97)

σ: Stefan-Boltzmann constant ($5.67*10^{-8} W/m^2K^4$)

Of these factors, the angle-weighting factor is the most difficult to calculate, when dividing the environment into several surfaces. Fanger (1970) proposes a procedure for the angle factor calculations of simple shapes, which is not capable of handling complex urban forms; therefore simplifications are necessary in modeling.

There are several procedures for calculating T_{mrt}, both in models and in the real world. In case of measurement, today, an accurate on-site mean radiation temperature measurement technique exists, which includes all radiation fluxes, angle factors, human shape and so on (Hoeppe 1992). However, this technique requires a great deal of time and budget. Ali-Toudert and Mayer (2006) conclude that these difficulties explain the usual focus on the air temperature and air humidity in comfort-related studies, as these are easier to measure.

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[5] A surface with identical temperature in all its points at a given time

2.4. Human Comfort Indicators

Several indicators have been suggested in order to incorporate some or all of these factors into one measurable quantity, therefore allowing us to compare human thermal comfort in different situations. Humidex, short for Humidity Index, is used by Canadian meteorologists and shows how hot the weather feels to an average person by combining the effect of heat and humidity (Canadian Center for Occupational Health and Safety 2013).

$$\text{Humidex} = \text{Air temperature} + 0.5555 \times (6.11 \times e^{5417.7530 \times \left(\frac{1}{273.16} - \frac{1}{\text{dewpoint in kelvins}}\right)} - 10)$$

This index reflects the human discomfort due to excessive heat and humidity. When the Humidex ranges 40 to 45 generally everyone will feel uncomfortable and if it goes beyond 46 many types of labor must be restricted (Stathopoulos 2009). However this index has the disadvantage of considering neither radiation nor air speed.

There are some multivariable regression models, which are derived empirically to calculate thermal comfort, based on the four mentioned parameters. Although these models are accurate in predicting thermal comfort but since they are based on subjective comfort votes given by individuals, they have the disadvantage of being restricted to the type of environment and climate in which the study took place (Johansson 2006).

PMV (Predicted Mean Vote) is another indicator of thermal comfort. This index forecasts the mean response of a larger group of people according to the ASHRAE thermal sensation scale (Table 1).

Table 1: ASHRAE thermal sensation index

-3	-2	-1	0	1	2	3
Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot

Fanger (1973) expresses the PMV index as:

Equation 3:

$$\text{PMV} = (0.303\ e^{-0.036M} + 0.028)\ L$$

Where:
PMV = *Predicted Mean Vote Index*

M = *metabolic rate*

L = *thermal load*[6]

PPD or Predicted Percentage Dissatisfied is yet another indicator of thermal comfort, based on the PMV (Figure 5). It is a quantitative measure of the thermal comfort of a group of people at a particular thermal environment (Olesen 1982).

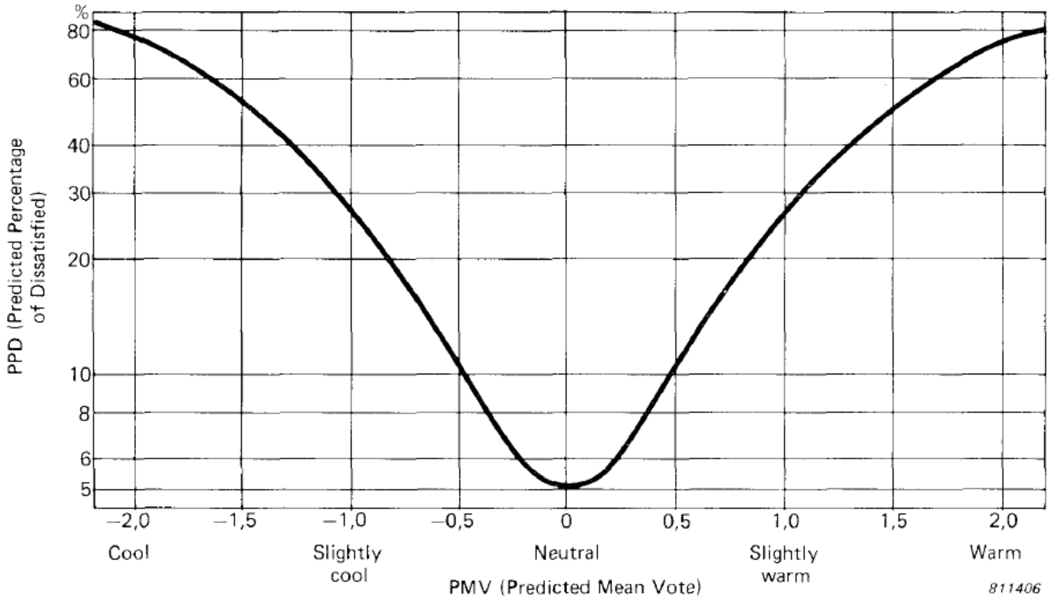

Figure 5: PPD in relation to PMV (Source: (Olesen 1982))

It should be noted that under any circumstances, 5% is the lowest percentage of dissatisfied that can be expected. In other words, the thermal condition is not appealing to at least 5% of the users, in any given condition. The reason for this fact is the differences in the metabolism and energy balances of the users.

PET (Physiological Equivalent Temperature) is another index, which tries to incorporate all climatic variables into one quantity. This evaluation parameter was developed from the MEMI energy balance model for the human body (Munich Energy balance Model for Individuals). Höppe (1999) identifies this indicator as *"the physiologically equivalent air temperature at any given place (outdoors or indoors) and is equivalent to the air temperature at which, in a typical indoor setting, the heat balance of a human body is maintained with core and skin temperature equal to those under the conditions being assessed"*. In other words, PET is the air temperature at which, in a typical indoor setting ($T_{mrt}=T_a$, VP=12hPa, $v=0.1\ ms^{-1}$), the heat balance of the human body, assuming light

[6] Defined as the difference between the internal heat production and the heat loss to the actual environment - for a person at comfort skin temperature and evaporative heat loss by sweating at the actual activity level (The Engineering Toolbox 2011).

activity and a heat transfer resistance of the clothing of 0.9 clo, is maintained with core and skin temperature equal to those under actual conditions (Höppe 1993). For a person who is sitting and wears typical indoor clothing, PET is defined between 18 and 23°C (Matzarakis, Mayer and Iziomon, Applications of a universal thermal index: physiological equivalent temperature 1999).

Although these indices have shortcomings (e.g. their inability to predict thermal comfort in dynamically changing conditions), they provide a comprehensive picture of the environment. They are not limited to any specific time or location and they consider most of the environmental variables.

When thermal comfort is considered in urban design, a difficulty usually comes up: The conflict between seasonal needs. In summer protection from the sun is necessary while in winter, more solar access is desired. Ali-Toudert and Mayer (2006) argue that this theoretically implies preferred compactness in summer and openness in winter. However, Oke (1988) argues that a compromise between these conflicting interests can be reached.

It should be noted that the assessment of urban climate is subjective, rather than objective. It depends on the opinion of individual subjects about the environment, which they have been exposed to. People have expectations from their climate and these expectations are a mixture of general preferences and short-term needs that may vary according to the actual physical (heat balance) and psychological (e.g. work or leisure) states of the subject (Bruse 2002).

Another disadvantage of these indices is that they do not consider the subject experiences of his previous environment. For example, after spending some time in a shady environment, subjects will consider sunny locations comfortable, even if after some time, the climate conditions lead to a thermal discomfort.

2.5. Climate change and thermal comfort

The conditions that cause disease and mortality in populations as a result of the warming climate and related extreme weather events are at one end of the spectrum of impacts of the design of buildings and cities on people. While it is important to avoid dangerous thermal conditions, it is also vital to avoid discomfort.

In a future age, when few people on Earth can afford to run machines, it is necessary that designers relearn the fundamental lessons of the relationship between humans, cities and the climate.

The fundamental assumption of the adaptive approach is expressed by the *adaptive principle*: If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort. These reactions may be:

- Through unconscious physiological changes; i.e. sweating, shivering, muscle tension and changes in the blood flow
- Through behavioral responses; i.e. consciously through the addition or removal of clothing, or semi-consciously such as changes in posture or moving to a more comfortable spot

Baker and Standeven (1995) offer a robust characterization. They identify an *adaptive opportunity* afforded by a building or city that will affect the comfort of its occupants. The statement is that the more opportunity occupants have to adapt the environment to their liking, the less likely are they to experience thermal stress and the wider will be the range of acceptable conditions.

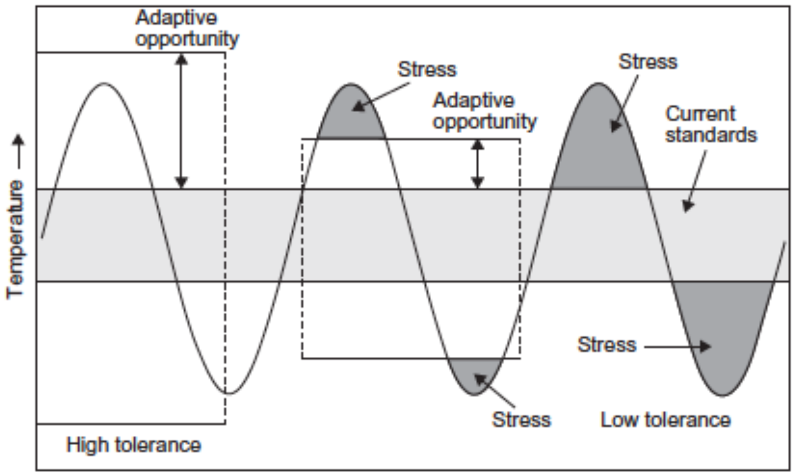

Figure 6: Effect of adaptive opportunity: The greater the opportunity to control the environment, the less likelihood of thermal stress (Source: Baker and Standeven, 1995, cited in Roaf et al. 2009)

In case of buildings, adaptive opportunity can be interpreted as the ability to open a window, draw a blind, use a fan and so on, and in case of cities, the ability to move to a shaded area.

2.5.1. Urban Climate features

2.5.1.1. Urban form and surface materials

The influence of the urban canopy layer on the urban climate is generally agreed upon (Arnfield 2003). The street canyon, which is a typical urban street with rows of buildings on both sides of it, is a common element in the canopy layer, especially in the city centers (Johansson 2006). This element is determined by the ratio between the height of the facades and the width of the street (H/W ratio), or the average building height in case of asymmetric canyons.

Surface albedo, which regulates the short-wave radiation absorption, is related to the color of the surface and varies between 0.3 for light colors and 0.9 for darker surfaces.

Oke (1987) identifies thermal admittance as the key parameter in determining how much of the absorbed radiation will be stored in the sub-surface: the lower the thermal admittance, less heat will be stored in the material while more energy will be released as sensible heat (Johansson 2006). Thermal admittance increases with the density of building materials and moisture content of soils (Evans 1980). Dry soils have lower thermal admittance than common urban surfaces, such as asphalt and concrete, while moist soils have equal or higher values of thermal admittance than those of urban materials (Szokolay 2004). However, due to irregular urban geometry, the surface exposed to the air (the active surface), is considerably larger in urban areas in comparison to the rural areas (Oke, Spronken-Smith and Grimmond 1999).

2.5.1.2. Vegetation and green spaces in urban areas

Trees and vegetation affect urban climate in two different ways. First, they will provide shade against solar radiation –including direct, diffuse and reflected radiation from buildings- and decrease air temperature through keeping urban surfaces cooler.

Secondly, the vegetated soil has much more capacity to release energy through evaporation and transpiration. Therefore, green areas within cities tend to be cooler than built-up areas, especially during nights (Johansson 2006, 40).

The high permeability of vegetated soils increase the precipitation absorption, therefore decreasing the risk of floods.

2.6. Urban climate adaptation measures

Considering adaptation to climate change, the urban design guidelines in literature cover a wide range of aspects, such as urban form, street network orientation, shade in public spaces, building types and the properties of surface materials. In some texts, guidelines deal with other aspects as well, e.g. adopting green spaces.

Golany (1996) suggests that in order to maximize shading by buildings narrow alleys should be designed in a zigzagging fashion. According to his investigations, this type of alleys will not only provide protection against unpleasant winds, but also remain warm at night. Some other intellectuals suggest wider east-west oriented streets and narrow north-south oriented ones (Givoni 1998).

When it comes to urban form, most of the suggestions are in a way to increase shade in public places, e.g. varied building heights, and since much of the shade is achieved through high H/W ratio, they tend to opt for higher ratios. Shading of the sidewalks by architectural features, e.g. overhanging roofs (Givoni 1998) and rooftop shading screens (Swaid 1992) is also promoted. The significant role of shade trees in cooling the air through evapotranspiration is pointed out in many sources.

In order to decrease the energy absorption by the urban fabric, Givoni (1998) identifies low surface temperatures as an important factor. He suggests shading, vegetation and high surface reflectivity to achieve this.

In the relevant literature, there are several measures proposed to minimize climatic stress in hot arid cities (summarized in (Alcoforado and Matzarakis 2010)):

- Reduce solar gain: In order to avoid air conditioning, strategies to minimize heat stress must be practiced. Trees, arcades and narrow streets, different shading devices, high-albedo building surface materials and green roofs can be used to reduce radiation, therefore diminish heat stress.
- Maximize solar gain in winter: Building materials and wall thickness should be chosen correctly, so that diurnal temperature variations inside the buildings would be minimized by taking advantage of the heat storage capacity of the walls.
- Increase evaporation: Increasing the extent of evaporation will balance net radiation at the ground surface by latent heat loss. Reducing non-permeable surfaces and irrigated greenbelts within the urban boundaries will realize this goal.
- Minimize wind exposure: When the buildings have the smallest possible building envelop, their exposure to wind is minimized.

Compact geometry and short walking distances are suggested to avoid extreme conditions. Pearlmutter et al (2007) argue that "*increased urban density, while serving to increase radiative trapping and storage of heat within the urban fabric, also reduces thermal stress during critical daytime hours*". The reason behind this effect is high thermal inertia of the buildings and great diurnal temperature amplitudes, with relatively low minimum temperatures (Alcoforado and Matzarakis 2010).

Chapter 3: Research Problems, Questions and Goals

In this chapter, research problems, questions and goals are identified. In Iran, as in many other developing countries, climate issues are generally not considered in urban design. In his thesis, Johansson (2006) summarizes two separate studies performed in Saudi Arabia and reports "*Current urban design in Saudi Arabia has led to an undesirable microclimate around buildings. [The main reason for this is] a prescription of an extremely dispersed urban design where the provision of shade is totally lacking, … the urban form is characterized by gridiron plans with wide streets where the detached, low rise "villa" is the most common type of house*".

The predicted changes in the climate of the Iranian cities in the hot and dry area are assumed to worsen the adverse microclimate. If the climate-conscious urban design is not promoted in the context of Iran, the negative impacts of climate change on cities might be inescapable.

3.1. Research problems

Undeniable signs of climate change and global warming and lack of adaptation and mitigation plans in Iran call for an immediate reconsideration of the urban planning and design paradigm. The main problems of this research are as follows:

3.1.1. Negative impacts of climate change on human thermal comfort

Although a change in climate will lead to a spectrum of impacts on cities and their residents, in this research, human thermal comfort is at the center of attention. In hot and dry climate of Iranian central cities, climate change will most likely result in higher temperatures and lower air humidity, therefore decreasing thermal comfort in urban areas. The consequences of a reduced thermal comfort on human health are quite serious. As mentioned before, heat stress not only increases the chance of heat stroke and heart disease, it diminishes both mental and physical performance.

In developing countries such as Iran, poor outdoor thermal comfort receives little attention. The urban poor, who spend most of their time outdoors and cannot afford to mechanically regulate their living environment, are the most sensitive group of the population, in face of a changing climate.

Negative social and economical impacts are also possible consequences of poor thermal comfort. Unpleasant climate would limit time spent outside to only when necessary, i.e. shopping and commute to work, and decrease outside social activities, i.e. meeting people in public places (Gehl 2001). Outdoor commercial activities, i.e. open-air markets would also suffer.

It is also discussed that poor urban microclimatic conditions lead to deteriorating indoor comfort indirectly (Johansson 2006). A major consequence of this fact is the increased use of air conditioning, resulting in higher energy costs for the citizens. Frequent power disruption and increased air pollution are also consequences of increased power consumption.

Moreover, in warm climates, as the air conditioning units cool the interior of buildings they emit sensible heat to the exterior, thus exacerbating outdoor conditions.

3.1.2. Absence of climate considerations in urban planning and design

It is widely argued that urban microclimate and outdoor thermal comfort are generally ascribed little importance in urban planning and design processes. In words of Aynsley and Gulson (1999) *"urban climate is often a largely unplanned outcome of the interaction of a number of urban planning activities [...], and outcome for which no authority and no profession takes responsibility"*. Moreover, knowledge about climate issues is missing among Iranian planners and designers, and also suitable design tools are simply absent.

In Iran as a developing country, rapid urbanization implies the uncontrolled growth of cities, in which climate aspects are completely disregarded. A main reason behind the uncomfortable thermal situation of the planned settlements in Iran is the uniformity of urban design regulations throughout the country. Although Iran hosts a myriad of climates, the main design regulations governing the urban development are the same in all the provinces and cities. There are minute differences in the local regulations, i.e. lower plot coverage in smaller cities, but the overall trend is the same. Furthermore, these guidelines are often inspired by planning ideals from other countries and consequently poorly suited to local conditions.

3.2. Research aims and questions

Improving human thermal comfort in Iranian cities, as a major part of adaptation to climate change, is of great significance. The main aim of this thesis is to deepen the knowledge about the relationship between urban design and climate change adaptation and mitigation in the context of Iranian cities with hot and dry climate through studies conducted in Kerman. Moreover, highlighting the impact of urban planning on the urban microclimate, specifically outdoor thermal comfort is a goal of this research.

Furthermore, increasing the awareness of climate considerations among urban planners and designers and decision makers is also intended in this dissertation.

To achieve these research goals, the following questions should be answered:

- How are the cities and their livability affected by the climate change? Specifically Iranian midsize cities in the semi-arid regions.
- Which characteristics of traditional Iranian Urbanism can be used to adapt contemporary cities to climate change?
- Are the German strategies and approaches also applicable in Iran? And if so, how can they be implemented in the extensive adaptation plan of Kerman?

Based on the results of this research, guidelines and recommendations for climate-conscious urban design, in Kerman and other Iranian cities with similar climate, can be developed.

3.3. Research scope and limitations

This research concentrates on how climate change affects human thermal comfort and how urban design can annul these changes. The urban canopy layer is the main domain of this study, however, most of the calculations are performed at the pedestrian level, roughly 1.5 m above ground level.

The main focus is on the predominant residential urban form, however, it does cover mixed-use areas to a lesser extent. The main focus of this research is on urban design and the detailed planning level rather than on comprehensive planning aspects, such as the location of urban areas within a city. This study does not include public spaces such as parks and it is limited to street design. Urban vegetation is explored only for shading purposes.

Kerman has been selected as the case study for this research, but the results can be generalized to all Iranian cities with hot and dry climate.

Thermal comfort is estimated by calculating a comfort index based on simulated environmental parameters. This study does not include field studies on subjective thermal comfort as perceived by pedestrians.

Since the effect of air pollution on thermal conditions in moderately polluted cities such as Kerman has proven to be small, air pollution and its consequences on thermal comfort and human health are not included in this study. Moreover, as the effects of anthropogenic heat on the urban climate has been found to be negligible, it is not considered in this study. Last but not least, indoor thermal comfort is not treated in this research, while it is indirectly affected by the urban climate.

As the future climate is expected to be milder in winters and harsher in summers, and since the summer period is generally longer than the winter period in the selected region, the simulations of this research only analyze the human thermal comfort in summer situation.

This research is in not a comparative case study review as the two cases, Kerman and the Ruhr area, are very different in nature. The discrepancies in these contexts are beyond a possible simple comparison. However, the cases have been studied on a more conceptual level. Furthermore, this research does not seek to assess the design and execution of InnovationCity Ruhr project. The two German projects serve as examples of possible adaptation activities.

Chapter 4: Research Methods and Data

4.1. Research Methodology

This research is based on deductive reasoning and it is multidisciplinary in character. Its main objective is to understand how climate change will affect human wellbeing in Kerman, and how cities in hot and dry region of Iran can adapt to these changes through altering the physical characteristics of their built environment, based on the current and previous experiences of German and Iranian adaptation activities and mechanisms.

It was necessary for the design of the research process to combine various research methodologies in order to provide responses to the research questions. The general design could be classified as experimental, although it includes a combination of the following research strategies (Groat and Wang 2002):

- Literature review and qualitative study
- Simulation

In the overall approach of this research, the quantitative (simulation) methodologies dominate over the qualitative methodology. Within each methodology, different methods or techniques have been used.

The aim of the *literature review* part of this study was to establish a solid theoretical background, and to create a toolbox of strategies recommended and adopted in the German and Iranian cases.

The aim of *qualitative study* was to obtain basic knowledge of the urban planning and design processes, including the role of climate and thermal comfort aspects.

The three methodologies were combined in different ways in order to obtain more reliable research results. This mixed methodology helped in identifying the strengths and weaknesses of current urban codes with regard to climate-conscious urban design.

The aim of *numerical simulations* was to cover a wider range of urban design in determining the effects of variations of built environment on the human thermal comfort. Moreover, using a simulation methodology enabled the isolation of independent variables in order to determine their respective impact. It is also possible to forecast the effects of new urban design options on the microclimate and to improve the design from a microclimate perspective.

4.2. Obstacles in research

The difficulties met during the course of this research can be divided into two main groups:

- Obstacles in data collection: The city authorities in Kerman refused to provide the requested data. They claimed that the Iranian Intelligence Ministry has banned the government agencies from supplying any kind of data and information to Iranian students studying abroad, fearing spy activities. Therefore, even the simplest data (i.e. per capita amounts of green spaces), had to obtained through personal connections or observations. Moreover, the university libraries visited to gather information on the latest local research in the related fields did not cooperate fully. The researcher had to provide them with extra proof of studentship in Germany, and even then he was not allowed to access the entire database or make copies of the texts.
- Difficulties in microclimate modeling: The microclimate modeling software used in this research is ENVI-met, which only harnesses one core of the CPU, therefore taking longer on simulations, even on basic previews. To tackle this problem several simulations were run simultaneously on the same system, which had its own problems.

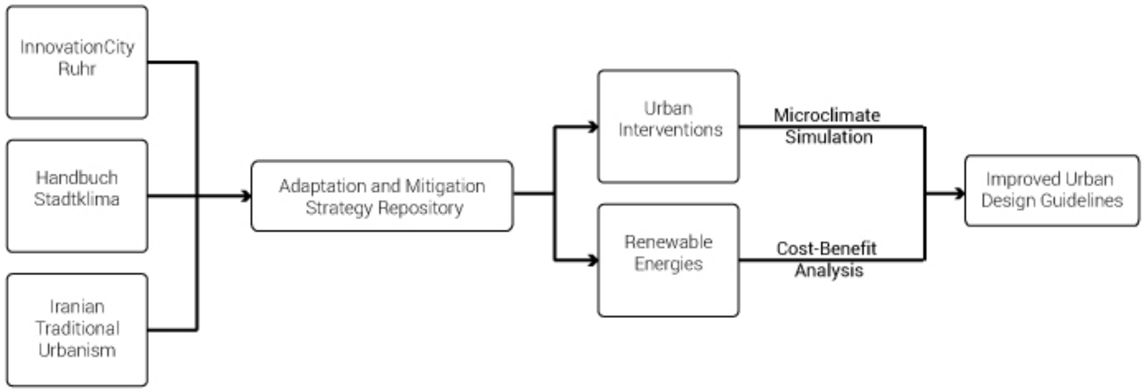

Figure 7: Analysis and Conclusion workflow

4.3. Literature Review and Qualitative Study

In order to establish a solid theoretical framework for this research, extensive investigation has been performed on current literature, concerning issues related to research questions. Climate change, adaptation and mitigation, successful examples around the world, traditional adaptation activities in Iran, along with necessary tools, such as research methods and simulation technics were in the focal point of this literature review.

Since climate change has attracted a great deal of attention in the past years, there has been a massive amount of publication in this realm; therefore it was necessary to be selective. The main criterion behind this selection was the validity of the source. It was decided to focus on official sources, i.e. official IPCC reports or other literatures developed by the same authors, rather than focusing on less reliable sources with unconventional and uncontested ideas. Online publications were the main source of this section of the investigation. The main library of TU Dortmund and the library of the faculty of spatial planning were used in obtaining the relevant literature. The interlibrary service was used on some occasions to access references which were not available online, nor in the library.

Regarding the Iranian traditional climate regulating mechanism, there is a vast spectrum of publications available, mostly in Persian. However, the majority of these literatures focus are mainly about climate and architecture, and they cover urban climate only as a secondary topic. Nonetheless, in the past few years, with the separation of Architecture and Urban planning and design as two independent academic disciplines in Iranian universities, enough focus has been devoted to urbanism. Sources for this part of literature review were purchased during the field trip visits in Iran.

Moreover, the qualitative study included an analysis of existing regulations related to urban design, as well as interviews with professionals involved in disaster management processes.

The documents studied in the analysis of urban design regulations consisted of guidelines on urban design aspects, such as building heights, spacing between buildings and the permitted portion of the ground to be occupied by buildings. The outcome of this design code review was information on:

- Maximum building heights
- Minimum street width
- Maximum plot coverage
- Minimum setbacks
- Maximum floor area ratio (FAR)
- Maximum allowed extension into street space (balconies)

The urban design codes were translated into maximum H/W ratios for the street. These regulations were further analyzed to determine whether they facilitate or hinder climate conscious urban design.

In order to gather information on the German side of the story, a broad online search was performed for related materials. Unfortunately, most of the literatures available in this field are in German. Google Translate service was used to compensate for author's intermediate knowledge of German language.

The Center for Information and Counseling[7] (ZIB) of the InnovationCity Ruhr project was visited in Bottrop. Valuable insight into the project was acquired through the network established in that visit. Finally, the first official draft of the Master Plan for the InnovationCity Ruhr project, published in October 2013 was selected as the reference for this specific project.

As mentioned before, in order to investigate the nature of disaster management processes in the context of Kerman, interviews were designed to be performed with professionals active in this field. However, because of the reasons discussed in Chapter Three, only one of these interviews was carried out, with the chief of the General Department of Disaster Management. This interview was informal and conversational, and no predetermined questions were asked, in order to remain as open and adaptable as possible to the interviewee's nature and priorities.

[7] Zentrum für Information und Beratung

4.4. Urban climate and human thermal comfort simulations

On both issues of street microclimate and outdoor comfort, rather to conduct experimental studies, there has been a greater tendency to use numerical modeling methods (Ali-Toudert and Mayer 2007b). According to Arnfield (2003), the popularity of numerical modeling over the last decades is largely attributable to the costly and time consuming exercise of directly recording all the relevant meteorological variables using accurate measurement methods.

Ali-Toudert and Mayer (2007a) argue that there are two main benefits in conducting thermal comfort analyses through numerical methods. Firstly, in order to highlight the connection between the physical urban structure, the microclimate and comfort, the numerical modeling is highly suitable. Therefore, the results of these models can be translated into practical design guidelines easily. Secondly, since it is rather fast and low-cost, this method allows comparisons between numerous case studies.

Continuous observations of radiation fluxes surrounding a human body in open spaces are lacking in particular. Although globe thermometers as integral instruments are not accurate indoors, they commonly replace these observations in the studies. However, collection of extensive data is required in order to validate the results obtained from the modeling of urban microclimates (Arnfield, Two decades of urban climate research: a review of turbulence, exchange of energy and water, and the urban heat island 2003).

As mentioned before, in this particular case, the changes in climatic situation are towards milder winters and harsher summers. During winter, the minimum temperature will increase and during summer the maximum temperature will also increase. Precipitation will also decrease dramatically. It will all lead to a more comfortable thermal situation during winters (in comparison to the current situation) and less thermal comfort during summers. Therefore it was decided to focus on the human thermal situation during summer period.

Moreover, since subjects are more adapted to cold in winter, the thermal stress is mainly an issue during summer times. It may be argued that removal of clothing is as effective during heat waves, as is the addition of more clothing during cold times, but it should be noted that, in this particular case, many forms of clothing, especially for women, are not accepted culturally or may be considered against the law. Thus, people can adapt themselves much easier to the cooler environment, rather than in warmer climates.

4.4.1. Micro climate analysis

In order to investigate the efficacy of urban interventions on the thermal comfort at the pedestrian level, model-based simulations were used. A sample environment was modeled in ENVI-Met. Several alternatives were simulated in these models and the results were exported to Rayman. This software calculates many environmental indicators, such as PMV, SET*[8] and PET. Physiological Equivalent Temperature or PET was selected as the main assessment indicator for this research. An upper discomfort limit is proposed by Ahmed (2003) and (2006) which corresponds to PET = 33°C. This limit has been used as a reference point through out this study.

4.4.1.1. Envi-met

ENVI-met is a 3D model, which seeks to replicate the major atmospheric processes that affect the microclimate. This model simulates wind flows, turbulence, radiation fluxes, temperature, humidity and other parameters, based on the fundamental laws of fluid dynamics and thermodynamics.

ENVI-met has a very high spatial and temporal resolution, and simulates buildings with various shapes and heights, as well as vegetation. This leads to a better understanding of the street level microclimates. Although ENVI-met requires few input parameters, it is capable of calculating most important meteorological factors, even the mean radiant temperature that is needed for thermal comfort analyses. ENVI-met also gives a good approximation of T_{mrt} (Bruse 1999), which is vital in calculation of human thermal indices.

Because of the high complexity of the processes used in ENVI-met, the models are very slow. This also limits the resolution or the size of the area of interest, as well as the calculated timespan (Fröhlich and Matzarakis 2013). Since the total number of the grids has a maximum limit, in order to cover a wider area, grid sizes should increase, therefore reducing the spatial resolution. This limitation in the resolution leads to inaccuracy. When the grid size is set to 2 m, all objects turn into cuboids. Larger objects are divided into several smaller cubes and smaller objects are ignored. Moreover, calculations of radiation and airflow are also affected by this reduced resolution, however, since these

[8] Standard Effective Temperature

inaccuracies are clear to observe in results, they can be excluded from the analysis.

In this study, ENVI-Met V.3.1 was used. Unfortunately, this version can only use one core of the computer's processor, therefore complicated and large models take a long time to simulate on this platform. In this research, some models took as long as 70 hours to complete.

4.4.1.2. RayMan

The RayMan model has been developed in the Meteorological Institute of the University of Freiburg in Germany. This model is developed to simulate the short- and long-wave radiation flux densities from the three-dimensional surroundings in simple and complex environments. RayMan is in fact a freely available radiation and human-bioclimate model. The aim of the RayMan model is to calculate radiation flux densities, sunshine duration, shadow spaces and thermo-physiologically relevant assessment indices using only a limited number of meteorological and other input data (Matzarakis, Rutz and Mayer 2010).

The model takes complex urban structures into account and is suitable for several applications in urban areas such as urban planning and street design. This model calculates T_{mrt} as its final output, which is required in the human energy balance model, and thus also for the assessment of the urban bioclimate, with the use of thermal indices such as predicted mean vote (PMV), physiologically equivalent temperature (PET) and standard effective temperature (SET*).

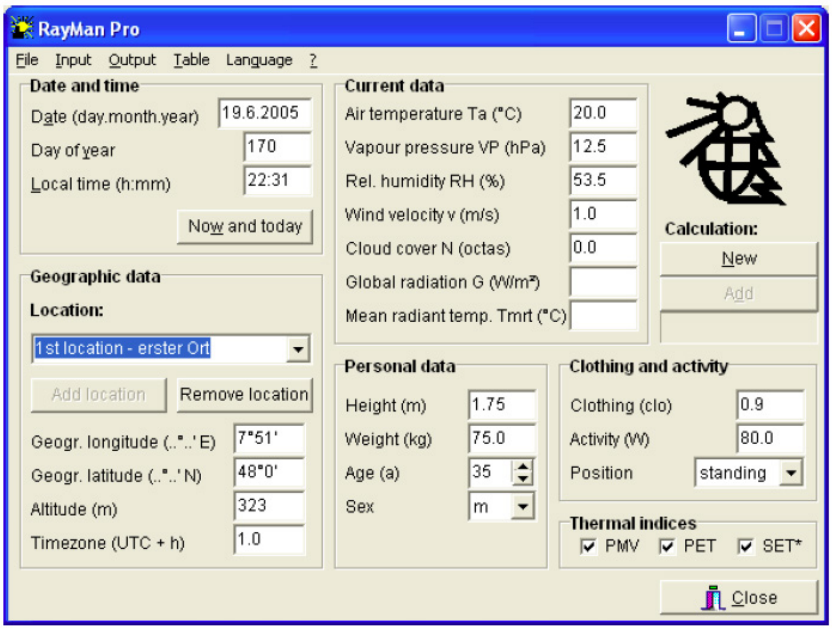

Figure 8: Main interface of RayMan (Source: (Matzarakis and Rutz 2005))

The model has been developed based on the German VDI-Guidelines 3789, Part II (environmental meteorology, interactions between atmosphere and surfaces; calculation of short- and long-wave radiation) and VDI-3787 (environmental meteorology, methods for the human bio-meteorological evaluation of climate and air quality for urban and regional planning. Part I: climate). Experimental studies have already validated the results of the RayMan model (Matzarakis, Rutz and Mayer 2000).

RayMan is also capable of calculating sunshine duration with or without sky view factors; estimating daily mean, max or total global radiation; and determining shaded areas.

When using the computer software "RayMan" an input window for urban structures (buildings, deciduous and coniferous trees) is provided. For the estimation of sky view factors, the possibility of free drawing and output of the horizon (natural or artificial) are included. Moreover, in order to make the calculations of the sky view factors possible, the input of fish-eye-photographs has been included in the model. Free drawing can include the amount of clouds covering the sky and their impact on the radiation fluxes can be estimated (Matzarakis 2001).

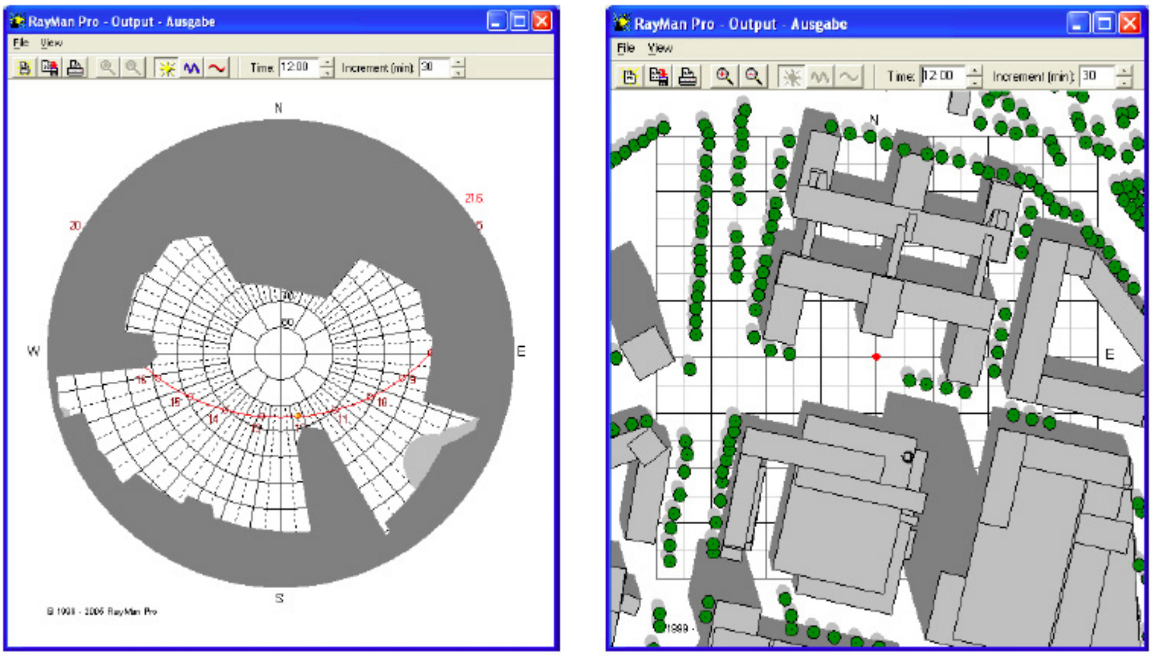

Figure 9: Example of sun path (left) and shadow (right) for June 21 for a complex environment (Source: (Matzarakis and Rutz 2005))

The most important question about radiation properties on the micro scale, in the field of applied climatology and human biometeorology, is whether or not an object of interest is shaded. Therefore, shading by artificial and natural obstacles is also added to this model.

Horizon information, such as the Sky View Factor, needs to be known to obtain sun paths. Calculation of hourly, daily and monthly averages of sunshine duration, short wave and long wave radiation fluxes with and without topography and obstacles in urban structures can be carried out with RayMan. Data can be entered through manual input of meteorological data or pre-existing files. The output is given in form of graphs and text data (Matzarakis and Rutz 2005).

4.5. Model Calibration

In order to make the results of these model-based simulations more credible, the model had to be calibrated. The input values have to be changed slightly, so that the output values turn out to be a more accurate representation of reality. In order to do that, a preliminary model had to be developed, based on an actual site, where climatic data were available. The necessary data were collected from the local office of the Department of Meteorology for a period of 24 hours. These data were observed every two hours, in a certain location of the city and consisted of temperature, relative humidity, wind speed and direction (Table 2).

The same area was modeled in ENVI-Met and the simulations were run for 14 hours, beginning at 6:00 am. The observed data were used as the input data for the software and other input data that were not available, such as soil humidity, were set to default values. The results of the preliminary model were compared to the actual observed data. In the first stage, the relative humidity in the model was much higher than expected. Through trial and error, a new set of input variables were developed, which produced acceptable and valid results. The changes were mainly done in the humidity of the higher levels of soil and the timing steps of the simulation. Since ENVI-met is a prognostic model, it only requires start input values, therefore this calibration had to be done to make sure the modeled environment is following the same pattern as the specific case in reality.

The practical details of the ENVI-Met model used in this study are explained comprehensively in chapter eight.

Table 2: Observed climatic data for the preliminary model

Time and Date	Temp (°C)	Relative humidity (%)	Wind speed (m/s)	Wind direction	Wind direction	Pressure (hPa)
13:30 2013.06.25	38	9	3,1	North	0	1011
15:30 2013.06.25	39	8	3	East	90	1012
18:30 2013.06.25	39	8	3,1	North, North-west	330	1009
20:30 2013.06.25	34	14	3,1	North	0	1009
22:30 2013.06.25	32	17	3,1	North, North-west	337	1011
00:30 2013.06.26	29	20	2,7	South	180	1011
03:30 2013.06.26	27	24	4,2	South	180	1011
05:30 2013.06.26	23	29	4,3	East, South-east	112	1012
07:30 2013.06.26	24	27	1,9	East, South-east	112	1013
10:30 2013.06.26	35	9	6,1	West	270	1013
12:30 2013.06.26	37	7	3,1	North, North-east	22	1013
14:30 2013.06.26	38	9	4,2	West	270	1012
17:30 2013.06.26	39	7	4,2	West	270	1009

4.6. Calculations of human thermal comfort indices

As mentioned before, the output data of microclimate simulation models were exported to RayMan. For each scenario three sets of data were available, one for each receptor. These datasets included simulated climatic values with 30 minutes time interval and consisted of temperature, humidity, wind speed and direction and T_{mrt}. As the Mean Radiant Temperature was already calculated in ENVI-Met with high accuracy of the Sky View Factor, its calculation was skipped in RayMan.

The outcome of RayMan calculations was then analyzed in MS Excel, where charts and graphs were developed for further investigation.

4.7. Energy Production Simulations

In order to explore the feasibility of mitigation strategies through production of renewable energy in the context of Kerman, two methods were used. At the first stage, two renewable sources of energy were chosen for further investigation; Wind energy and solar energy. The potential of these energy sources was determined in this specific context, through various literatures.

The next stage was feasibility assessment. Based on the results of the potential study, it was decided to focus on solar energy, specifically two rather common technologies in this sector, which proved to have a high potential in Kerman; Solar water heating and Solar electricity generation.

In both cases, a basic system suitable for a family of four was selected as the subject of cost-benefit investigation. In case of solar water heating, a simple cost-benefit analysis was performed, based on the current data acquired from valid sources. The aim of this part of research was to find out if this technology is financially feasible.

Regarding solar electricity generation and Photovoltaic technology, due to the sophistication of the matter, RETScreen software suite V.4 was used.

4.7.1. RETScreen

RETScreen 4 is an Excel-based clean energy project analysis software tool that helps decision makers quickly and inexpensively determine the technical and financial viability of potential renewable energy, energy efficiency and cogeneration projects. This software is capable of considering many variables in its calculations. It is developed by Natural Resources Canada and is free of charge.

RETScreen significantly reduces the costs (both financial and time) associated with identifying and assessing potential energy projects. These costs, which occur at the pre-feasibility, feasibility, development, and engineering stages, can be substantial barriers to the implementation of Renewable-energy and Energy-efficient Technologies (RETs).

RETScreen is the most comprehensive product of its kind, allowing engineers, architects, and financial planners to model and analyze any clean energy project. Decision-makers can conduct a five step standard analysis, including energy analysis, cost analysis, emission analysis, financial analysis, and sensitivity/risk analysis.

The technologies included in RETScreen's project models are all-inclusive, and include both traditional and non-traditional sources of clean energy as well as conventional energy sources and technologies (Natural Resources Canada 2013). A sampling of these project models includes: energy efficiency (from large industrial facilities to individual houses), heating and cooling (i.e. biomass, heat pumps, and solar air/water heating), power (including renewables like solar, wind, wave, hydro, geothermal, etc. but also conventional technologies such as gas/steam turbines), and combined heat and power (or cogeneration).

Table 3: Input assumptions

Cell module type:	mono-Si
Cell module manufacturer:	Sunpower
Cell module model:	SPR-320E-WHT
Cell module efficiency:	19.6%
Tracking:	Fixed
Slope:	30°[9]
Azimuth:	0°, Due south
Annual solar radiation horizontal:	1.91 MWh/m^2
Annual solar radiation tilted:	2.03 MWh/m^2
Power capacity:	3.2 kW
Nominal operating cell temperature:	45°C
Temperature coefficient	0.4%/°C
Solar collector area	16 m^2
Inverter:	Single Phase, 3.3 kW, SMA
Inverter efficiency:	97%
Length of construction:	1 month
Interest during construction:	17%
National inflation:	31%
Cell module price:	15,680,000 Rials per panel
Number of modules:	10
Inverter price:	123,200,000 Rials
Installation and engineering costs:	30,000,000 Rials
Project lifetime:	25 years
Annual electricity exported to the grid:	6 MWh
O&M[10] costs:	1,100,000 Rials per year
Miscellaneous losses	1.0%
Transportation costs	5,000,000 Rials

Fully integrated into these analytical tools are product, project, hydrology and climate databases (the latter with 6,700 ground-station locations plus NASA

[9] For maximum annual energy production, roughly equal to the local latitude
[10] Operations and Maintenance

satellite data covering the entire surface of the planet), as well as links to worldwide energy resource maps. An extensive database of generic clean energy project templates is also built in to help the user rapidly commence analysis. Table 3 demonstrated the input values used in these simulations.

In order to make these calculations more realistic, the prices in these calculations were officially quoted from Mehrabad Company[11], a local supplier of renewable energy production tools and machinery, in September 2013. In designing photovoltaic systems, the slope and azimuth of the modules can be designed in several ways, each maximizing the energy production in a certain period, i.e. during summer. For these simulations, the maximum annual power production was assumed as the reference point for the calculation of slope and azimuth.

The government reported the inflation rate as 31% (Statistics Center of Iran 2013), however, there are several reports that the actual inflation is far more than the reported value. Nevertheless, in this study, the official inflation values were adopted.

Based on current and predicted future trends in Iranian energy market, the following scenarios were simulated in RETScreen:

Table 4: Scenarios

Energy export escalation rate:	10%, 15%, 20%
Debt interest:	4%, 12%, 24%
Feed-in-tariff:	Base: 316.18 Rials/KWh Improved: 3225 Rials/KWh

[11] http://mehr-abad.ir/

Chapter 5: Case Studies

In this study, Kerman, as a typical medium-sized city in the semi-arid region is selected as the case study within Iran. Furthermore, since Bottrop is the pilot city for several adaptation projects, it was elected as the case study within the region Ruhr. This chapter provides insight on these cities and their backgrounds.

5.1. Kerman, Iran

5.1.1. Geography and History

Kerman is the capital city of Kerman province, located at the south east of Iran. As of 2010, the population of the city was 562,133 people (Statistics office of Kerman 2010). The area of the city is 139.97 km^2 therefore the population density is 4016.09 inh/km^2, which is almost two times more than the urban density of Dortmund.

Kerman was founded in the 3rd century AD and has had a colorful past during these years. Kerman was enclosed by a wall all around it with six entrance gates (Figure 10). Each gate was coupled with two brick towers. There were other towers along this wall (every 300 to 500 meters) but they were made out of clay. This wall, which was ten kilometers long, was accompanied by an eight meters deep moat. But even these fortifications were not enough to keep the enemy away. Many kings have ruled over the city and it has seen bloodshed carried out by Arabs, Mongols and Turkmens.

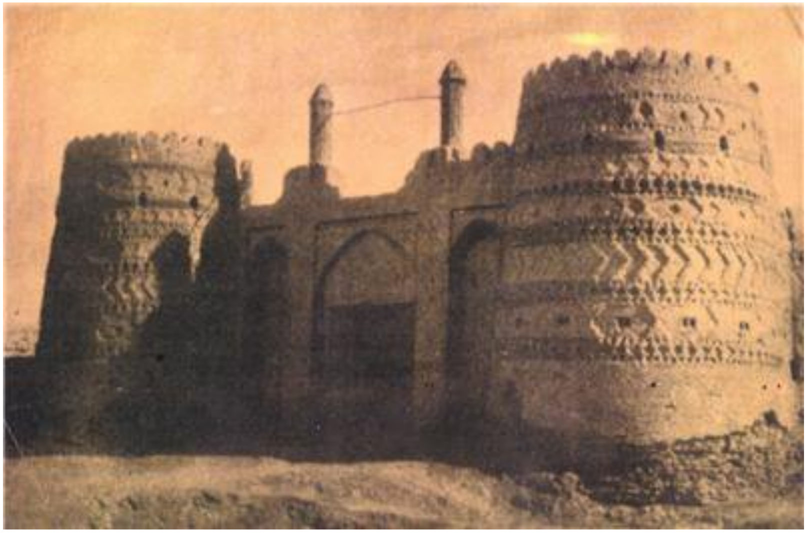

Figure 10: Gabri Gate (Source: (NLIA 2013))

In 1793, Lotf Ali Khan defeated the Qajars and in 1794 captured Kerman. But soon, Agha Mohammad Khan besieged him in Kerman for six months. When the city fell to his hands, angered by the popular support that Lotf Ali Khan had received, all the male inhabitants were killed or blinded, and a pile was made out of 20,000 detached eyeballs and poured in front of the victorious Agha Muhammad Khan. The women and children were sold into slavery, and the city was destroyed over ninety days. (Pirnia and Eghbal Ashtiani 2003)

The present city of Kerman was rebuilt in the 19th century to the northwest of the old city, but the city did not recover to its former size until the 20th century.

Kerman expanded rapidly during Safavid dynasty in 16th century. Safavid appreciation of arts led to a boom in construction of public spaces in Kerman. Bazaar of Kerman, which is the longest Bazaar in Iran (Kermani 2013), was constructed in this period and every king would add another piece to this magnificent structure. Similar to other cities in the Iranian hot and dry climate, bazaar acted as the city`s backbone. Public baths, schools, caravanserais and other public buildings were situated in the vicinity of bazaar.

After the destruction of the city, new development started outside of walls. The old town followed a linear format imposed by the bazaar, but the new construction did not have any special structure. This outgrowth is limited towards east, as mountains block it. Most of the construction takes place towards west, along the main road to Tehran, the capital of the country. This linear sprawl is quite clear in aerial photos (Figure 11).

Figure 11: Aerial view of Kerman (Source: Google Maps 2014)

Nowadays, the old city is mostly run down. The buildings around bazaar, which were residential landmarks, are now only home to illegal immigrants or storage facilities for merchants based in bazaar. Many of these buildings are historically valuable but left alone. In the old town, commercial buildings occupy the plots next to the main streets and deep inside the blocks is utterly deserted.

Figure 12: Ruins in the heart of city (Source: Author)

Kerman, due to its closeness to the Central Kavir (the central desert) could not have an economy based on agriculture. Moreover, the Spice Road, which connected Europe to India, passed through the city (Figure 13). Therefore the economical structure of the city was based on the bazaar. In conclusion, the spatial role of bazaar in Kerman's structure, has taken effect from economical and social role of the bazaar (Masoudi Nejad 2005).

Figure 13: The main traditional commercial roads (Source: (Habibi 1997))

5.1.2. Urban design in Kerman

The future of the built environment in Iran is planned through several different plans, both in terms of spatial and temporal scale, and the level of detail. The development of these plans is funded by the Ministry of Roads and Urban Development and is carried out by authorized consultants through public bids. The spatial planning system in Iran consists of four main categories:

1- National level (The National Spatial Planning Project)
2- Regional level (The Provincial Structural Plans)
3- Urban level: which includes land uses, urban density, connections, …
    a. Urban Master Plan (for medium to large cities)
    b. Guideline plans (for small cities and rural areas)
4- Local level: which addresses urban issues on a much more detailed scale through urban design
    a. Basic comprehensive plan: for different districts of the city (both current and future developments)
    b. Confined comprehensive plan: for urban regeneration, rehabilitation and revitalization of current urban fabric or pre-development of new cities

c. Specific comprehensive plan: for particular purposes, such as road network development

In this research the focus is on the urban master and comprehensive plans and the climate considerations in the development of such plans.

In 1950s, the first master plans were designed for some Iranian pilot cities by American and German consultants. In 1964, the High Commission for Urbanism was established and assigned with the task of managing and approving the urban master plans throughout the country. During the 3rd development plan before the Islamic revolution, master plans had been approved for 17 Iranian medium to large cities. However, most intellectuals believe that the master plans as we know them today were introduced with the 4th development plan (Pakzad 2002) (Hashemi 1988).

In 1971, the government decided that every city larger than 25,000 in population has to have a master plan and guidance plans should be developed for smaller towns. Before the Islamic revolution in 1979, 70 master plans had been advised for the Iranian cities (Pakzad 2002), and in 20 years, this number increased to 616, covering 97% of cities with population greater than 50,000 and 87% of smaller towns (Department of Planning and Budget 1999).

The High Commission for Urbanism has specific regulations for the development of these master plans. This includes an elaborate checklist of different analyses and studies that need to be performed as a preliminary step in the design process. "Geographic and Climatic Analysis" stands at the top of this list, however it is still widely believed that these analyses are not incorporated in the final plans and are neglected more or less. On the other hand, the second step in the protocol for comprehensive planning, right after analysis, is Priority Assessment, which seems to ignore climatic issues at least in this case study.

At the moment, the city of Kerman has a master plan that was originally designed in 1983 and several comprehensive plans for different districts (Sharestan Consultants 2013). The master plan has been amended several times. These comprehensive plans consist of detailed reports on one hand, and maps, tables and figures on the other hand. However, since there is no transparency in the planning system of Iran and public collaboration is alien to this regime, these plans have never been made public. The architects are asked to make an inquiry for the specific plot of land they are going to design, to make sure how their design should fit in with the overall comprehensive plan.

Nevertheless, some general rules regarding building properties and their geometries have been made public through the local chapter of the Iranian Structural Engineering Organization and the municipalities. These regulations are complementary to the National Building Codes and cover:

1- Plot coverage, FAR[12], setbacks, balconies:
   Maximum plot coverage is 60% of the whole plot area. The buildings should cover the northern part of the plot. In case of land plots with two free sides (access to two streets) this coverage is increased to 70%. If the street is between 16 and 35 meters wide and if the land use is designated as commercial, the plot coverage can be increased to 100%.
   Maximum allowed extension of balconies (in addition to 60%) in private courtyards is 1.5 meters. Balconies in public streets narrower than 8 meters are forbidden. When the street is 8 to 12 meters wide, balconies can extend 80 cm into the street, however the distance between the street ground level and the bottom of the balcony should be at least 3.5 meters. In streets wider than 12 meters the balcony could extend 1.5 meters with a minimum height of 2.5 meters from the street floor level.
   In industrial, cultural, educational, religious, administrative and sport land uses the maximum plot coverage is 40%. In case of medium to large urban developments, which includes residential apartment blocks and complexes, this plot coverage is also 40%, nevertheless it is possible to increase the land coverage to 50% and in some cases to 60% if the developers accept to pay extra permit fees.
2- Maximum building heights
   In this table the maximum number of building stories and height is explained. It should be noted that these heights are only for buildings outside the historical district. There is a comprehensive plan for the historical district that addresses building heights in this specific area.
   The allowed building height is a function of the street width. In case there are multiple street accesses to the plot, the wider street width is considered.

[12] Floor Area Ratio

Table 5: Maximum allowed building heights

	Street width	Maximum number of stories	Equal height in meters	Max H/W[13]
1	Less than 6	One floor	3 - 4	0.67
2	6 to 8	3 + piloti or basement	9 - 12	2
3	8 to 10	4 + piloti or basement	12 - 15	1.87
4	10 to 12	5 + piloti or 6 + basement	18	1.8
5	12 to 18	6 + piloti or 7 + basement	21	1.75
6	More than 18	7+ piloti or 8 + basement	24	1.33

3- Parking provision:

For each residential unit, at least one roofed parking space should be foreseen in residential projects. General regulations concerning access ways, entrances, story heights and so on apply here as well.

4- Skylights and patios:

There are no guidelines concerning the openings in the building tissue specific to this site. However, designers are reminded to follow National Building Code.

5- Elevators:

By these regulations, it is obligatory to design elevators for buildings higher than four stories.

The urban fabric of Kerman can be divided into three distinct groups, which are also clearly visible in the Master Plan (Figure 14). The first group is the inner core of the city. This area consists of Kerman bazaar and its adjacent spaces, along with the remains of what used to be the heart of the old city. As mentioned before, most of the structures in this area are not maintained, deserted and in very poor condition. However, in recent years, the municipality has tried to create incentives for private investors to invest in the regeneration and rehabilitation of this area. Moreover, there are specific detailed plans for the redevelopment of this historic fabric. This area is outlined by purple in Figure 14.

[13] As the building mass is located on the northern part of the land plot, in east-west streets, the northern side consists of walls marking the plot boundaries (usually 3 meters high), therefore the H/W ratio would be half of the stated value

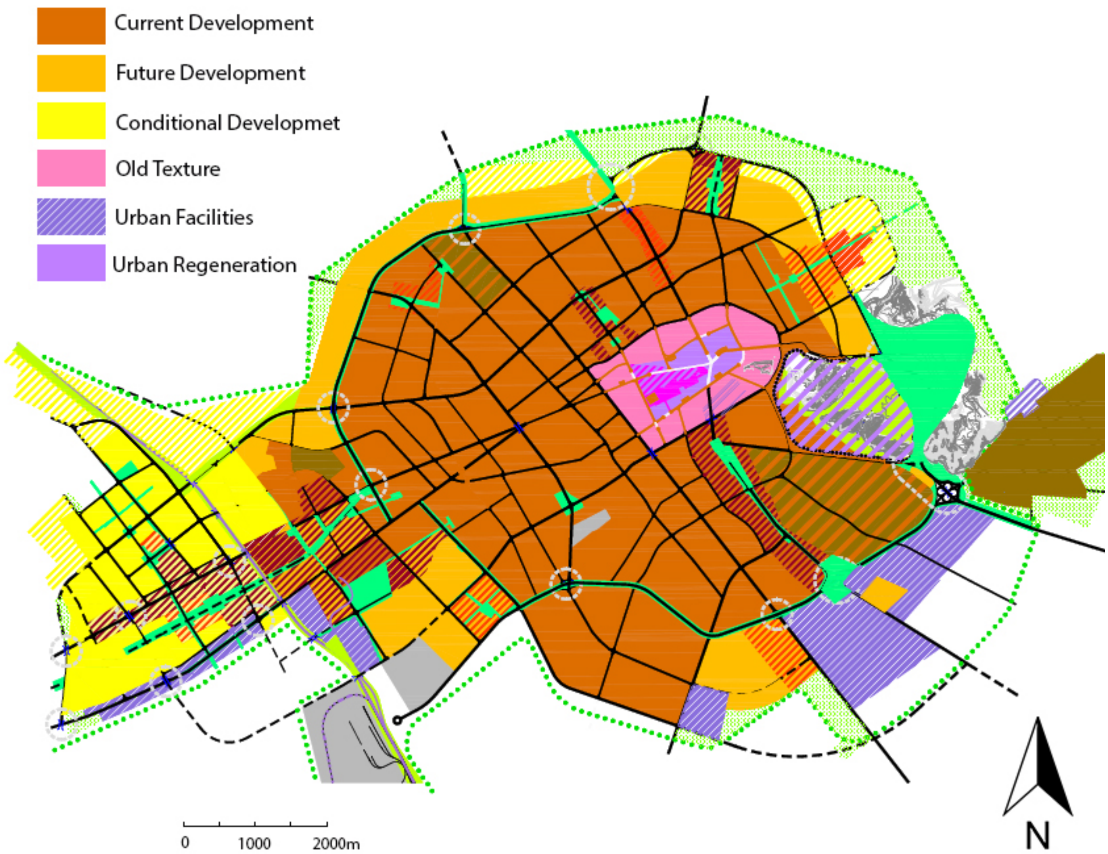

Figure 14: Urban Master Plan of Kerman (Source: Sharestan Consultant Engineers)

The second space typology of Kerman, which indeed covers the majority of urban structures in this city, is single family houses, one or two stories high. As seen in the Master Plan, the orange color dominates the city and encloses the inner core. In recent year, with the rising demand in housing and the boom in real estate market, a new trend has emerged. The owners of these houses, which are know as "*Villas*" in the Iranian planning culture, tend to demolish their houses and erect new apartment blocks instead. These demolished houses are sometimes very young, in some cases even 10 years old. Most of all, this phenomenon has disturbed the skyline in Kerman. What used to be a uniform skyline of buildings with rather the same height has turned into a broken skyline of adjacent tall and short buildings. Furthermore, it has created privacy issues. The residents of the Villa can no longer use their private courtyard freely, or comfortably, as taller buildings have visual access to it.

The last type of the urban fabric is the new developments in the peripheries of the city. Seen in the Master Plan as shades of yellow, these new developments are mostly apartment blocks in previously rural areas. Because of the market forces, this growth of the urban tissue is mostly towards west, and it is extending very fast. Because of the tremendous pace of development, urban services need to catch up with this urban growth. There are hardly any shops in these areas and the residents have to visit the more inner parts of the city, even for buying their simplest needs. Generally speaking, the public transport has an inferior state in Kerman. Especially in the peripheries, residents rely on their private cars for commuting. Nonetheless, the real estate value in this area is rising much faster than the rest of the city.

Private residents own most of the land area within the city limits. Therefore, when the municipality tries to enact an urban design project, there are many conflicts of interest that can arise. For example, if an urban project occupies private land, the municipality has to reimburse the owners for their lost property. There are two main problems here: a) the local municipality as an institution related to the government has its own official agents for estimating the value of the lost property, which is in most cases lower than the market value of that property and b) the municipality does not have enough liquidity for this reimbursement, therefore they offer land plots in the peripheries of the city, ex-agricultural plots with no immediate rise in the real estate value and ergo no attractiveness for the private owners.

As a matter of fact, for long-term projects, the only way to apply changes is through the building permits. For example, in case of widening a street, the municipality can only approve the extension application of the building permits on those properties that comply with the new regulations. This takes a long time to implement and in case of this example, leads to a non-unified urban body, where buildings have various setbacks according to their permit.

For more immediate projects, the municipality has to satisfy the owners through the mentioned mechanisms, which certainly lead to some conflicts. These conflicts of interests can last very long as the municipality does not have enough authority to enforce them, and has to act through the courts of justice, which take a long time.

All in all, in Kerman urban intervention projects are usually prolonged more than expected, which causes the project expenditure to grow over estimates. Therefore, in order to implement urban design projects in a timely fashion, a major restructuring in the authorities of the municipalities is much needed.

5.1.3. Climate in Kerman

As mentioned before, Kerman (30°17′N 57°05′E) is located in the hot and dry region of Iran. Meteorological data are available for this city, since 1950.

With the yearly mean precipitation of 166 mm, Kerman has an average of 90 freezing days per year. Table 6 demonstrated average minimum, maximum and daily temperatures during the year in Kerman. The rather huge discrepancy between mean maximum and minimum temperatures is a common feature of the climate of cities in arid regions. This difference is also present in the maximum and minimum daily temperatures and can reach as high as 25 degrees.

Table 6: Temperature readings in Kerman (Source: Department of Meteorology)

Month	Mean Max Temp	Mean Min Temp	Daily Mean Temp
January	11.8	-3.2	4.3
February	14.8	0.4	7.2
March	19.1	4.1	11.6
April	23.8	8.1	15.9
May	29.6	12.2	20.9
June	34.8	16.2	25.5
July	35.7	17.7	26.7
August	34.2	15.1	24.6
September	31.4	11	21.2
October	26.1	5.2	15.6
November	19.4	-0.1	9.6
December	13.8	-2.3	5.3

In the past years, there has been a steady drop in the amount of precipitation. These droughts have put extra pressure on deep water-wells and agriculture. They have been significant enough to be sensed by the general public, but they have been related to periodical droughts. Based on the observations and interviews carried out in this city, the general awareness of the climate change is nonexistent. Even that portion of the population that has heard of global warming and climate change, does not consider these concepts as matters relevant to their own lives. Even the members of the authorities that were met during the data collection visits, seemed to be not knowledgeable of the future climatic circumstances and how it would affect their responsibilities.

The office of research and development at the local department of meteorology has developed a climate model for the period of 2010-2039, based on LARS-WG stochastic weather generator. The output of this model could be used to produce daily site-specific climate scenarios for impact assessments of climate change. These two groups of raw climatic data, site observations and climate model, were further analyzed and used to create charts in order to predict the future trends in climatic situations of Kerman.

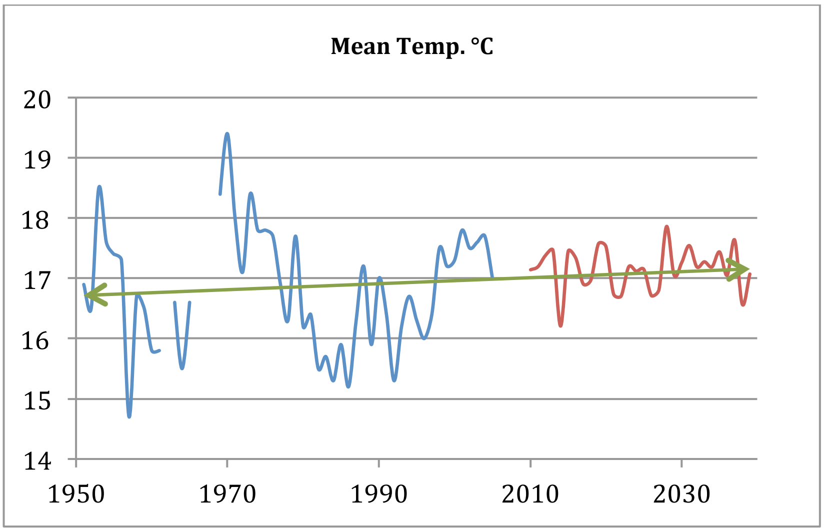

Figure 15: Mean Temperature

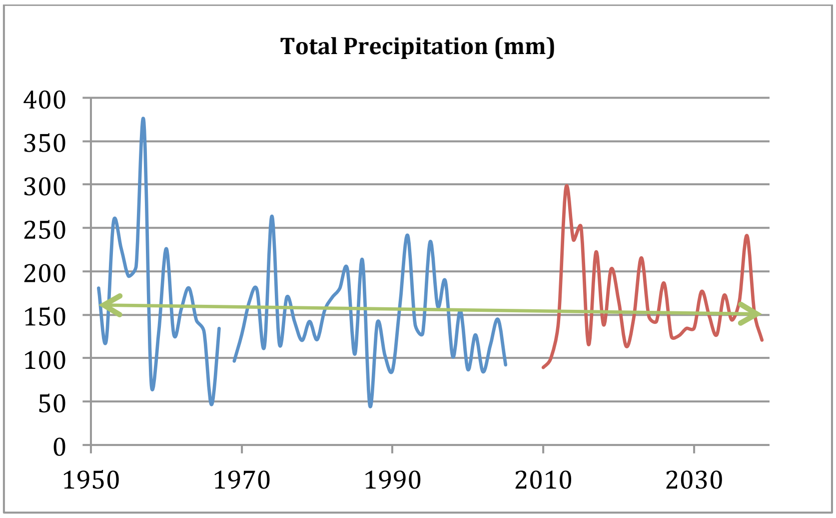

Figure 16: Total Annual Precipitation in mm

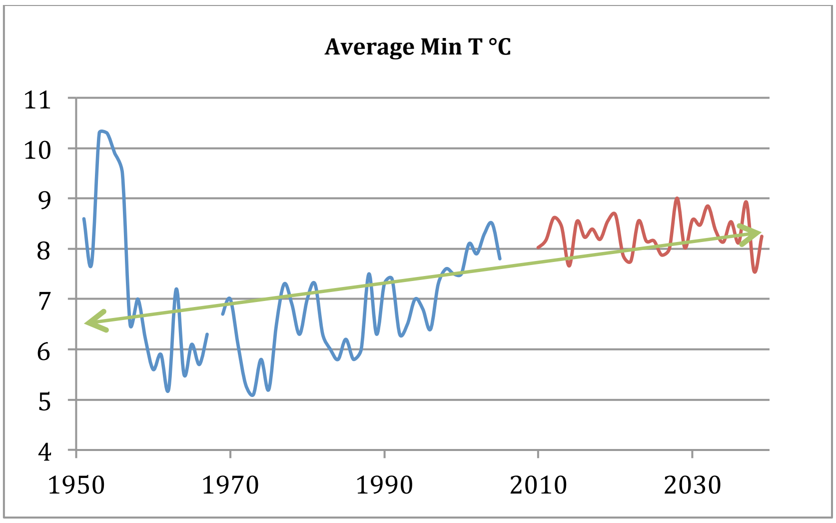

Figure 17: Mean Minimum Temperature

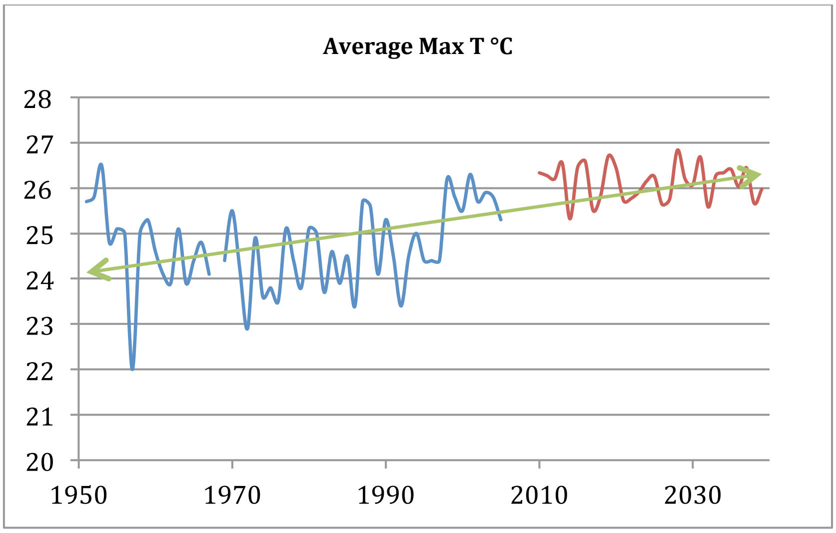

Figure 18: Mean Maximum Temperature

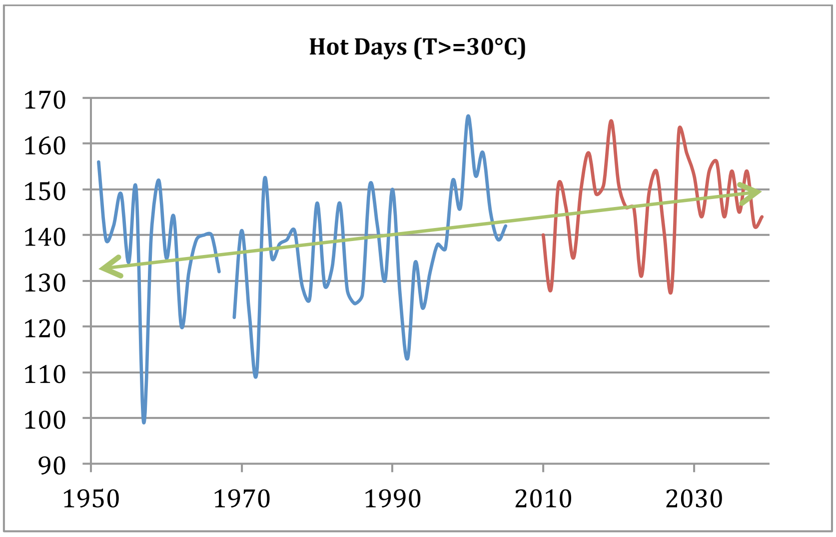

Figure 19: Annual Number of Hot Days

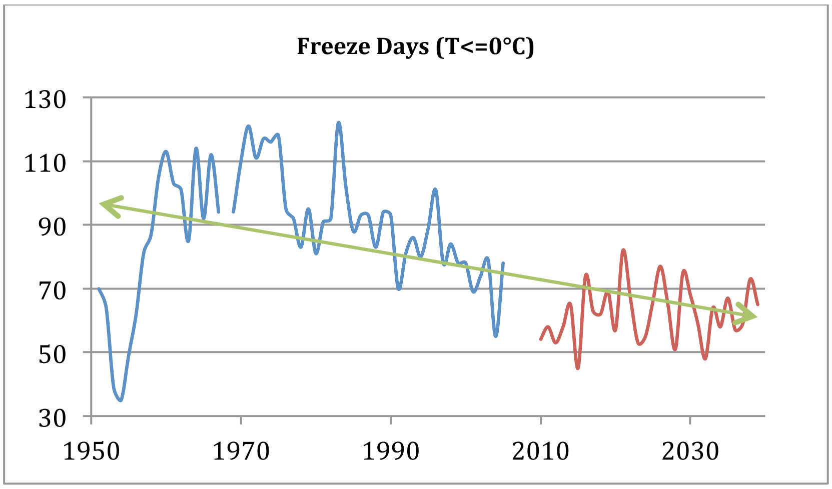

Figure 20: Annual Number of Freeze Days

Observed data 1951-2005 Modeled Climate 2010-2039 Linear ( )

Climate models along with the observed meteorological data present an increasing trend in air temperature. According to the trend line, mean daily temperature (Figure 15), average minimum temperature (Figure 17) and mean maximum temperature (Figure 18) are expected to rise in the following years. Moreover, the number of hot days with the temperature over 30°C will be increasing (Figure 19). In this research, the observed climatic data for the period 1951-2005 were acquired from the local branch of the department of meteorology.

On the other hand, the number of freezing days, when the temperature drops below 0°C will also decrease (Figure 20). Precipitation is also expected to decrease in the studied period (Figure 16).

Based on the analysis mentioned above, the future climate of Kerman is anticipated to be warmer and drier. There will be more hot days and less freezing days. Therefore, regarding human thermal comfort, it can be concluded that the thermal situation will be improved during winters while it is deteriorated in summers. Similarly, it can be argued that energy demand will decrease in winters while it increases in summers, assuming current circumstances in energy preservation. Although in this study there are quite heavy variations from the average lines, the general trend seems to be valid.

5.1.4. Disaster management and recovery in Kerman

In order to understand current practices in mitigation of and adaptation to climate change, the General Department of Disaster Management was visited. A detailed interview with the chief of the department was performed, and he explained the priorities in the activities of his department, the general procedure of decision-making, and future plans in face of climate change and disaster mitigation.

Since Kerman is located on the earthquake belt, powerful earthquakes have struck it almost on a regular basis. The deadliest earthquake to hit Iran in recent years happened on December 26, 2003, when a 6.6 magnitude quake struck Bam city (180 km away from Kerman city) and the surrounding areas in Kerman province. This destructive earthquake left 26,271 people dead and 30,000 injured.

Naturally, preparation for future earthquakes is at the top of the priority list of the disaster management authorities. In rural areas, since the construction technology is very primitive and there is absolutely no supervision on the construction process, the vulnerability to quakes is massive, and the need for disaster mitigation activities is undeniable.

According to this government official, more than 80% of their resources are dedicated to preparation activities against future earthquakes. Their efforts, according to the reports published by the same department, have been fruitful so far and the casualty rate has decreased in the recent years.

This department, which is responsible for the whole province, does assign some of its budget and resources to adaptation to climate change. However, these adaptation activities are directed towards drought affected agricultural areas and do not cover other aspects of climate change.

Apart from this department, which is a subordinate of the office of the province governor, there is one more institution related to disaster management. Recently, the mayor's office has established a specialized chapter dedicated to disaster management. However, so far the only activities performed by this department were urban flash flood management after an unexpected heavy rainfall in winter 2013 and disaster recovery educational courses for government employees. The administrators of this institute could not be reached for further investigation of their long-term goals.

Overall, in the city of Kerman, there are no specific plans for climate change adaptation and mitigation in an urban scale. The main reason behind this is the higher necessity of other life threatening factors in the eyes of administrators. If enough resources are assigned to this disaster related organizations, and awareness of the situation is raised in their leaders, there are opportunities for implementation of adaptation and mitigation strategies through these administrative bodies and institutions.

5.1.5. Climate change in Iran

According to Köppen's climate classifications, Iran can be divided into four different regions: Mild temperate climate (southern coasts of the Caspian sea), Cold climate (western mountain ranges), hot and humid climate (southern coasts of the country) and hot and dry climate (central plateau). The focus of this research is on the cities in the semi-arid and arid areas.

In Iranian central plateau, prevailing winds blow from north and west towards the equator, therefore rendering the climate very dry. Apart from that, high air pressure in these area leads to the displacement of air from the higher levels of the atmosphere towards the ground, which also increases the temperature and reduces humidity (Khalaj and Lashkari 2011). Although cloud coverage is usually very low, but fog, dust and sand storms in the afternoon may create a cover against solar radiation. Low humidity and the absence of clouds result in high fluctuations in temperature during day and night. In summer, the surface temperature of the earth may reach 70°C while at night the temperature drops rapidly to as low as 15 °C or even lower.

This plateau is bordered by Alborz mountain range in north and Zagros mountain range in the west, which block clouds from entering this region, thus decreasing precipitation. Dry air and lack of cloud coverage leads to higher solar radiation and increased evaporation. Dehghan Manshadi (2006) argues that this results in salty soil. Water shortage and salty soil endangers the vegetation, which increases the speed of hot and dry winds and results in more sand storms.

In this harsh desert conditions, human thermal comfort relies heavily on climate adaptation mechanisms in buildings and cities. Traditionally, thermal comfort has been provided through three main strategies: improved use of shade and wind, use of water, water management and solar radiation reduction (Golkar 2010).

Iran has a unique geography and ecosystem, enabling it to host a rich array of terrestrial and marine species, in its highly diverse climate and environment. However, environmental resources have been under great pressure during the past decades due to many factors, such as lack of precipitation, continuing droughts which put heavy stress and pollution on the already scarce water sources, urban and industrial air pollution, degradation of natural vegetation and soil erosion which all lead to a loss of biodiversity.

Moreover, as Iran is located in one of the most seismically active areas of the world, it is the sixth most disaster-prone country in the world. According to the official Second National Communication to UNFCCC (2010) an average of 4,000 people were killed and 55,000 affected annually by natural disasters over the last decade. They also estimate the losses due to earthquakes and hydro-meteorological hazards such as droughts, floods and landslides, at some USD 1.1 billion per annum, which is severe.

Iran had 1.6% annual population growth rate during 1997-2007 and 1.25% in 2011 according to CIA World Fact-book. However, a trend that is increasing at an alarming pace is the migration to cities due to droughts. As discussed earlier, recent droughts have decreased the agricultural output. Since most of Iranian rural population is employed in agricultural industries, with this downfall they have no option but to move to cities, where they may be able to find a job in the service sector. This trend can be partially attributed to climate change. Over the decade from 1996 to 2007 the Iranian urbanization coefficient had increased from 61.3% to 68.5% (Department of Environment 2010).

Based on meteorological data of 1960-2005, the temperature has risen between 2.5 and 5 degree Celsius on average. The increase in minimum temperature is more widespread than the maximum temperature. The differences are higher in large, heavily populated cities. The daily temperature variability has reduced almost everywhere, because of the pattern of higher minimum temperature.

Precipitation has decreased in most of the country. Especially in the west, northwest and southeast of the country, the number of days with precipitation more than 10 mm has reduced dramatically. Moreover, in the same period, the highest rates of decrease of wind speed are seen in central parts of the country, as well as northeast. In case of humidity, the dew point temperature has also decreased consistently.

According to the several climate models, higher temperatures nationwide with very little variations are predictable until the year 2100. Temperature rises between 0.4 and 4 degrees Celsius are foreseen. However, when it comes to precipitation, there are discrepancies in the results of different models (Watson, et al. 1997). HadCM2 predicts a rise in the amount of precipitation in the northern half of the country and a net loss in precipitation in the southern half. However, Lars-WG Weather Generator model predicts a 9% decrease throughout the country between 2010-2039, compared to 1976-2005 period (Department of Environment 2010).

The number of hot days will also increase in most parts of the country. The highest increase will occur in the southeast of Iran, by 44.2 days. The number of freezing days will also decrease. This model also predicts that the number of dry days will increase by 36 days in southeast.

Shifting migration ranges of insects and animals, modified flowering and fruiting cycles and species extinction are evidences of the impacts of climate change on biological diversity, which are already visible in Iran. Conversion of forests to agricultural lands, grassland, steppe, or desert in the north, west and center of Iran is also affiliated to climate change. An increased vulnerability to pests, fire and invasive species, threatens the rangelands of Iran (Department of Environment 2010).

The major climate change health related issues are malaria, leishmaniasis, cholera, diarrhea, air and water pollution and some natural disasters (EPA 2011). Apart from the outbreak of diseases, which may be intensified by the changing climate, usage of fossil fuels in urban areas creates air pollution that has longstanding effects on human health. In order to minimize the negative effects of climate change, easy access to clean drinking water, isolation and containment of sewage from water resources, as well as training and promotion of awareness among the rural population are effective and necessary steps in adaptation to climate change.

5.1.6. Iran and GHGs

According to the Greenhouse Gases Inventory, the total CO_2 emissions from different sectors in 2000 was about 375,187 Gg, with energy sector contributing of about 90% of the total emissions and industrial and forestry contributing about 8% and 2% respectively. The whole emission of CO_2 in the year 2000 in comparison with the amount of emissions in the year 1994 has increased with a compound rate of about 18% (at an average rate of 2.8% pro annum).

The Climate Change Performance Index (CCPI) is an annual publication by Germanwatch and Climate Action Network Europe. It evaluates the climate protection performance of 58 countries, responsible for over 90% of global energy-related CO_2 emissions. The most recent results (2014) illustrate that efforts are still insufficient to prevent dangerous climate change. Thus, no country received rankings one to three in 2014 (Burck, Marten and Bals 2013).

According to this reports, Iran has been at the bottom of this list since 2011 along with Kazakhstan and Saudi Arabia. In 2014, Iran ranked 56th out of 58 focus countries. Although it has raised one step from 2013, but the Iranian climate policy, emissions level, development of emissions, renewable energies and efficiency have been assessed as “very poor”.

While Iran possesses 1.18% of global GDP and 1.08% of world population, it produces 1.55% of the global CO_2 emissions (Burck, Marten and Bals 2013). As a lead producer of crude oil, Iran holds 1.62% of global primary energy supply.

5.1.7. GHGs Mitigation Policies

In developing the GHG emission mitigation assessment for the period of 2000-2025, three scenarios have been considered. (1) Business As Usual (BAU) scenario where all of the external variables of energy modeling vary based on

1994-2007 real trends; (2) Official Development Plan (ODP) where the governmental energy subsidy removal program during the 5th FYDP (Five Year Development Plan 2010-2015) was considered as a base for energy price variations; (3) Mitigation Scenario, where eight mitigation policies (MP) have been considered.

The mitigation policies are divided into two categories:

- National Mitigation Plan, which is funded by government and aims to reduce emissions about 30% in comparison with BAU scenario by 2025
- Internationally Funded Mitigation Action, which will reduce about 34% of emissions by 2025 in comparison with BAU scenario. These will be only feasible through the technical/financial assistance of international bodies.

These policies are the governmental objectives in the Iranian "Vision for Development 2025[14]".

5.1.8. GHGs Emission Trends

Under BAU scenario, the emissions in the energy sector will increase by almost 462% by 2025 in reference to 2007, while under ODP scenario this increase will be around 404%. According to the studies, introduction of strict energy pricing policies will impose a shock in the initial years, therefore decreasing the GHGs growth rate in comparison with BAU scenario. However, after 2015, the emission growth rate will fall back to the same rate as BAU. In 2010 the government implemented policies that would liberalize energy prices so that prices converge with FOB Persian Gulf prices.

The aggregate effect of all the mitigation policies is forecasted to result in 143% increase of GHGs emissions.

5.1.9. Mitigation Scenario Results

The mitigation scenarios in the non-energy sector are divided into four areas, industrial processes, agriculture, forestry and waste, of which the latter involves cities on a higher level.

It has been recorded that with the introduction of sanitary-engineering landfills with appropriate biogas collection and recovery systems 50-80% of the

[14] Vision for Development 2025 is a document, which outlines the development of Iran in cultural, scientific, economical, political and social aspects. This document is edited by Expediency Discernment Council and is expected to be executed in four five-year stages, beginning from 2005. According to this 20-year perspective document, Iran will be "Developed, ranking first in science, technology and economy in the middle east, with a revolutionary and Islamic identity, leading the Muslims of the world, and in a positive and fruitful cooperation with the international community". Although environment is not mentioned directly in this document, but complementary detailed plans have also included the environmental aspects.

methane emission from solid waste sector will be reduced. However, recycling, source separation and public participation need to be improved in the local society through workshops and training courses. In the liquid waste sector, it is assumed that the GHGs will be reduced by 36% by 2025 through wastewater reuse and recycling, and improvement of water consumption patterns via public training.

In general, Iran enjoys a significant potential for GHGs reduction, mainly in the energy sector, however, the mitigation activities in order to materialize these potentials depend on international financial and technical support.

The energy sector, as the major contributor to the GHGs emission, has the highest potential for mitigation as well; more than 1,270 million tons of CO_2 equivalent by 2025.

According to (Department of Environment 2010) the most effective mitigation policy in the energy sector relates to energy efficiency improvement of the end-use sectors. Therefore, plans to make the end-user sector less energy consuming by applying market policies such as provision of subsidies on efficient equipment for end users through targeting producers who manufacture low energy consuming devices, would be successful.

Moreover, policies on the supply side have a medium term effect and cannot compensate the increasing emission rate of the GHGs in the long term. The most important policy in electricity sector would be to increase the efficiency of power plants, which will result in an average emission reduction of 4.2% (Department of Environment 2010).

Although there is a huge potential for GHGs mitigation in the energy sector in Iran, there are also major barriers, such as lack of financial resources and access to climate friendly technologies.

5.2. The Ruhr, Germany

5.2.1. Geography and history

The Ruhr[15], or the Ruhr district, Ruhr region or Ruhr valley, is an urban area in North Rhine-Westphalia, Germany. With 5.1 million residents and 4.435 square kilometers area, it is the largest agglomeration in Germany and the fifth largest in Europe (Ruhr 2012). It consists of several large, industrial cities

[15] Das Ruhrgebiet

bordered by the rivers Ruhr to the south, Rhine to the west, and Lippe to the north. In the Southwest it borders the Bergisches Land. It is considered part of the larger Rhine-Ruhr metropolitan region of more than 12 million people.

Figure 21: The location of the Ruhr region in German (Source: (Ruhr City 2010))

From west to east, the region includes the cities of Duisburg, Oberhausen, Bottrop, Mülheim an der Ruhr, Essen, Gelsenkirchen, Bochum, Herne, Hagen, Dortmund, and Hamm, as well as parts of the more "rural" districts of Wesel, Recklinghausen, Unna and Ennepe-Ruhr-Kreis. As of December 31, 2011, the most populous cities were Dortmund (approx. 580.000), Essen (approx. 573.000) and Duisburg (approx. 488.000). The Ruhr area doesn't have an administrative center; each city in the area has its own administration, although there exists the supra-communal "Regionalverband Ruhr" institution in Essen. Historically, the western Ruhr towns, such as Duisburg and Essen, belonged to the historic region of the Rhineland, whereas the eastern part of the Ruhr, including Gelsenkirchen, Bochum, Dortmund and Hamm, were part of the region of Westphalia. Since the 19th century, these districts have grown together into a large complex with a vast industrial landscape, inhabited by some 7.3 million people (including Düsseldorf and Wuppertal). This conurbation is the fifth largest urban area in Europe after Istanbul, Moscow, London and Paris.

Figure 22: The Ruhr administration (Source: (Ullrich 2004))

According to the Regionalverband Ruhr, 6% of the region's area is built up. A total of 40.7% of the region's land remains in agricultural use. Forests account for 17.6%, and bodies of water and other types of land use occupy the rest. Because of its history, the Ruhr is structured differently from monocentric urban regions such as Berlin and London, which developed through the rapid merger of smaller towns and villages with a growing central city. Instead, the individual city boroughs and urban districts of the Ruhr grew independently of one another during the Industrial Revolution.

Replanting of brownfield land has created new parks and recreation areas. The Emscher Landscape Park[16] is a good example of these projects. This park lies along the River Emscher, formerly an open sewer. Parts of this river and its surroundings have undergone natural restoration (Emschergenossenschaft 2013). This park connects strips of parkland running from north to south, which were developed through regional planning in the 1920s, to form a green belt between the Ruhr cities from east to west.

England and Belgium were the origins of the early industrialization spread in the Ruhr. Along the Hellweg, the historical trade route developed by Charles the Great; a small number of dwellings grew up in this period. The purpose of mine exploitation in this region was initially to meet the local needs. The area consisted of 10 disparate administrative districts.

[16] Der Emscher Landschaftspark

The administrative districts valid today are remainders of the Prussian authorities. In the period of 1800 – 1870, with the boom in coal mining industry, the transport system of the Ruhr had to be improved to organize the transportation of coalmines' increasing output. It was during this period that the Ruhr was turned into a navigable river. The first English steam engines were copied and employed in the mining industry in the Ruhr. With the introduction of new machinery, the efficiency of mining processes was boosted enormously. Moreover, coal could be extracted from far deeper layers of the earth. Coal production doubled between 1815-30.

The extracted coal was transported on the Ruhr River to Ruhrorter Harbor, and from there it was shipped to its final destination. Coal and steel groups tried to safeguard their supply of raw material by increasing their number of mines. The region opened up from east to west and mining moved further northwards until reaching the Emscher River.

Working life on the industrial sites was dangerous and difficult. The social conditions of the social class were miserable. The new constitution of 1849 established a new class status for the bourgeoisie and cleared the way for the Industrial Revolution. The withdrawal of public authorities from the supervision of mining activities resulted in over production and heavy competition. In order to fulfill the increasing demand for living spaces, housing estates were built right next to the factories. Large numbers of people were living together in close quarters and the social networks were tightly knit (MVRDV 2004).

The period between 1870 and the beginning of the First World War is know as the Heyday of the Industrial Age in the Ruhr. More pneumatic hammers and drills were used in the coalmines. Dynamite was introduced to blast open the shafts. Furthermore, electricity was a groundbreaking innovation for the mining industry. Not only did it allow for the use of mining trams that could be worked by voltage power, it also brought light into the darkness of the shafts. Electrical pumps replaced the steam engines that controlled the waterways. In the larger cities of the Ruhr mining area, electrical trams replaced the conventional streetcars drawn by horses. The population of the Ruhr had increased tenfold by 1870 and up until 1914, an additional 700,000 immigrants settled on the banks of the Ruhr River. Workers from Poland, Masuria and Silesia were employed to fulfill the rapidly increasing demand for industrial manpower.

With the outbreak of the First World War, many workers of the Ruhr joined the German army for patriotic reasons. As a result, coalmines and steel factories lacked human labor. From 1915 onwards, in order to compensate the

50 percent drop in the number of employees, women were employed in almost all sectors of production. Even Dutch and Belgian prisoners of war were brought in to work the coalmines. In sharp contrast to the wretchedness and misery of everyday life, the colossal demand for arms and weapons boosted profits to inestimable levels.

In the Weimar Republic, the economic situation of the industrial sector in the Ruhr changed dramatically. It was cut off from the sources of raw material in Lorraine and Upper Silisea and also from the international markets. Moreover, the Treaty of Versailles brought a halt to commissions from the military, which was the most important source of income for this sector. Therefore, the armaments industry collapsed and unemployment figures arose. In 1925 alone, 35 coalmines were shut down. And until the summer of 1932, with the New York stock exchange crash of 1929, withdrawal of a great deal of American credit from the industrial sector in the Ruhr, and fierce competition in France and England, more than half of the production capacities of the coal mining and iron and steel works industry were shut down (Butzin 2005). The National Socialists suggested through their propaganda that their investment aid program was the only way out of the crisis.

Industrial magnets in the Ruhr backed Hitler and he came to power in 1933 (MVRDV 2004). Once again, the armaments industry became the main driving force of the economy. By 1937, steel production increased fourfold in comparison to the mid-twenties. With its coal and steel deposits, the Ruhr became the basis for the preparation of the nation for war. In 1941, the Ruhr is attacked from the air by allied forces and it was the civil population that suffered the most. Although these attacks damaged the industrial plants badly, they had a comparatively minor effect on production processes.

With the end of the war, the industry also came to a full stop. Almost half of all housing and the transport infrastructure had been destroyed. Initially coal production was only used to supply the local households. As many soldiers fell in combat or were prisoners of war, very few miners were active. Besides, foreign prisoners that used to work in the Ruhr had already left. However, under the strict supervision of the allied forces, the industry in the Ruhr is eventually modernized. Soaring economic growth goes hand in hand with a major change in the landscape and scenery along the Ruhr and the Emscher rivers. An extremely dense road network covered the Ruhr and mechanization eases working conditions in the mines (Kuball 2011).

In the years of post-war economic boom, the population of the Ruhr increased by about one million, as many people resettled from the East. The first guest workers from Yugoslavia and Italy were welcomed in the late fifties and early sixties to close the gaps on the job market.

With the lift of import duties, use of petrol was promoted and prices of coal decreased continuously. Therefore, mines were gradually closed down. By 1968, 54 percent of the mining capacities have been shut down and within the course of ten years, 320,000 miners lost their jobs (Bruckhoff, Schaefer and Krüger 2009).

Gradually, it got accepted that coal exports from Germany were no longer competitive on international markets and a gradual departure from coal mining was essential. Although the mining industry blocked establishment of the Ford plant in Cologne as a potential competitor for skilled worker, Opel opened a branch in Bochum and nuclear power plants were developed in Mülheim. The Ruhr Development Program was developed in 1968 as a first effort to manage the new structural change.

In the years 1974-75, steel production declined from around 40 to roughly 30 million tons and the number of employees is almost halved. The only chance for the survival of the steel industry in the international markets was to produce and refine high-grade steel. In the years following 1989 an auxiliary economic upswing was created by German unification and increased demand from the U.S. however, as international coal markets became even more competitive after the iron curtain was drawn back, this did not generate profits for the mining industry.

In 1998, the Deutsche Steinkohle AG was established as an umbrella to unify Germany's coalmines (Koch 2002). About 400,000 jobs had been lost in the Ruhr over the past 20 years, which brought the unemployment rate to roughly 15 percent.

Over decades, the region has transformed itself from a coal and steel industrial site to a service and culture-oriented metropolis. Today approximately 600,000 people of foreign origin, whose roots lie in almost 200 countries, live in the Ruhr Metropolis (Ruhr, Data & Facts 2012). Between mid-eighties and 2000, more than 200,000 new jobs were created, mainly in the services, telecommunications and IT sectors. Industrial sites that had become superfluous have since given way to large shopping malls and technology centers. Also, defunct coalmines are being reconstructed and used for ventures of various kinds, unless those that are torn down or preserved as monuments of the industrial age.

The establishment of the University of Bochum in 1963 was a starting point in the transformation of the Ruhr area to a location with future. This university was the first one in this region. Today, with its more than 20 universities, the Ruhr Metropolis has developed into one of the densest education and research sites. At the same time, the transformation to a center for knowledge, technology and service has taken place. Approximately 2.2 million people are employed in the region and earn 5.6 per cent of the German gross domestic product (Ruhr, Data & Facts 2012).

With the motto "Change through culture – culture through change", Essen was chosen as the European Capital of Culture 2010 to represent the Ruhr Metropolis. With its hundreds of museums, theatres, concert venues, festivals und industrial monuments, the Ruhr region is also a cultural agglomeration. These prerequisites and the special activities offered during the Capital of Culture year drew approximately ten million visitors to the Capital of Culture (Essen for the Ruhr 2011).

Globalization and sustainable economic growth call for the endorsement of a new regional identity (MVRDV 2004). The Ruhr will have to reshape and refine itself in order to keep up with future international competition.

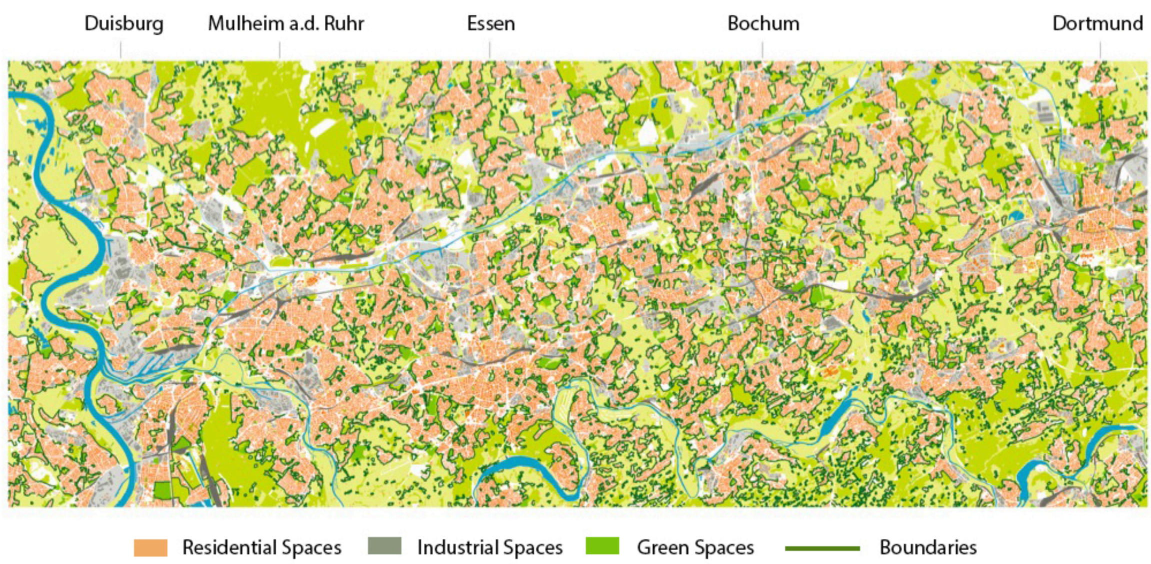

Figure 23: Mixture of urban spaces and green landscapes in Ruhr (Source: (Reicher, et al. 2011))

5.2.2. Urban Structure

A certain color, a light grey tone, prevails in the Ruhr region. From the city center to the suburbs, up to the next city, this color changes hardly, despite the green belts in between. Architecture is also monotonous; between city center architecture and architecture in the neighborhood, hardly any differences is visible, apart from some modern buildings or old mining towers that break this architectural monotony here and there (MVRDV 2004).

Central stations of the Ruhr are not very representative to tourists and lack historical importance (MVRDV 2004). They are very central and directly connected to the inner-city pedestrian area, except Bottrop. Although these stations used to lack modern shopping and fastfood areas, in recent years most of them have been reconstructed and very well equipped.

The central inner cities are very well paved, crowded during the day and lack resting zones. However, art objects are present around the city inner areas. While the neighborhoods are boring and monotonous as the prevailing architecture is often uninspired (MVRDV 2004). Also, there are not enough suitable playgrounds and niches. These neighborhoods are often very green in the south of the cities and less green in the north.

The Ruhr region is well integrated into the national rail system, the Deutsche Bahn, for both passenger and goods services. Also, All public transport companies in the Ruhr are run under the umbrella of the Verkehrsverbund Rhein-Ruhr, which provides a uniform ticket system valid for the entire area. The Ruhr has one of the densest motorway networks in all of Europe, with dozens of Autobahns and similar expressways crossing the region. The Autobahn network is built in a grid network, with four east-west (A2, A40, A42, A44) and seven north-south (A1, A3, A43, A45, A52, A57, A59) routes. The A1, A2 and A3 are mostly used by through traffic, while other autobahns have a more regional function. In general, this region enjoys a high level of mobility within itself.

There is no distinct border between the cities of the region, nor is there a specific center. In that way, Ruhr is very different compared with other metropolis areas of Europe. Reicher and her colleagues (2011) explain these differences in detail. In fact, it is demonstrated that the Ruhr has similar dimensions as other metropolitan areas, but its small scale and polycentric features require different structuring strategies.

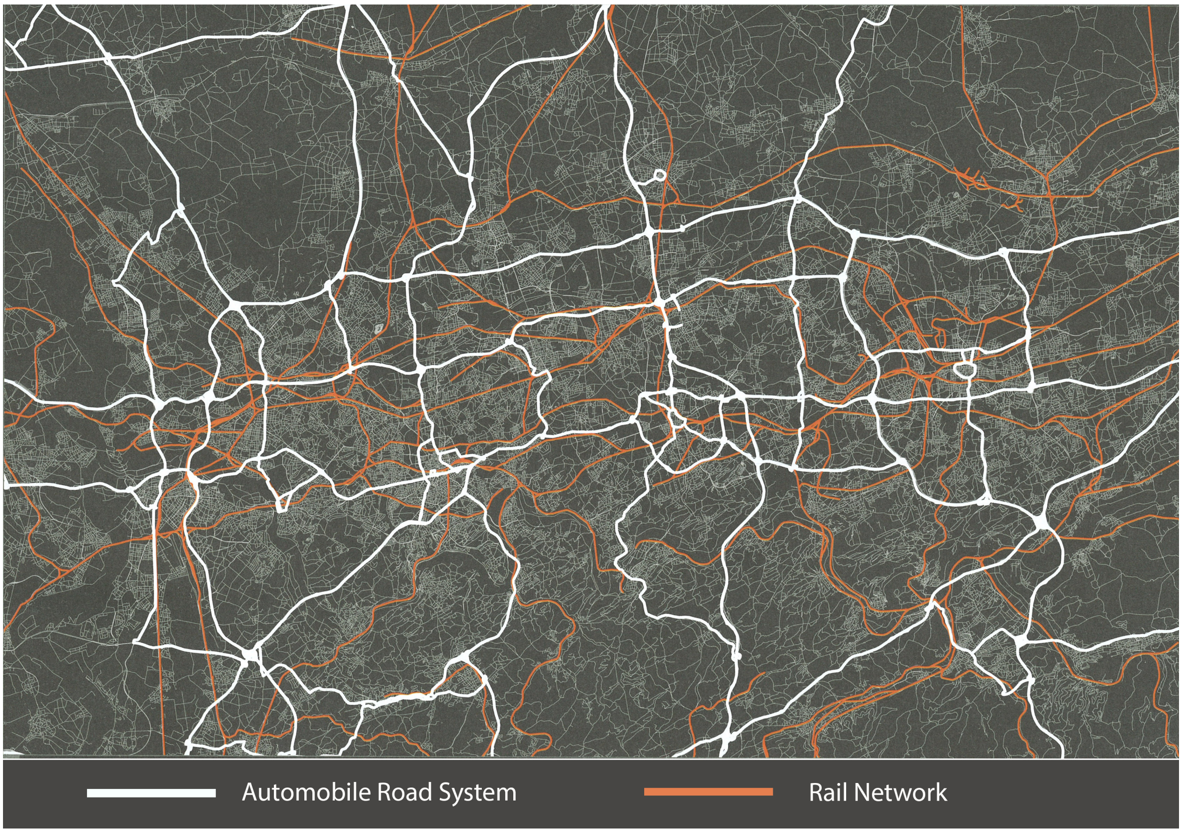

Figure 24: Road and Rail Network in the Ruhr (Source: Reicher et. al. 2011)

They argue that the diverse inner peripheries, which separate settlement zones from areas that have other very heterogeneous functions, is what distinguishes the Ruhr from other urban landscapes in Germany. Therefore, instead of having a single core and distinct border, Ruhr consists of multiple cores, each with its unique identity, and borders that are not distinct. They describe Ruhr as a "*Mosaic of very different scopes of action that fulfill their respective functions and stand for their own interests, without being steered by a regional parent institution in terms of what they do*" (Reicher, et al. 2011). Furthermore, they identify some turning points and barriers, which block development of the built environment in a certain direction. Highways, railroads, industrial areas and water bodies are some of these barriers. The abundance of these barriers in the Ruhr has led to a unique urban texture (Figure 25).

Moreover, they define "*Ruhrbanity*", as a term epitomizing a specific kind of new urbanity, setting apart the region from the traditional concept of urbanity, i.e. in London. It is the specific form of urbanity in the Ruhr, which has a polycentric structure and a chain of subspaces connected by constructional compacted traffic arteries such as the Hellweg.

Figure 25: Barriers in the built environment (Source: (Reicher, et al. 2011))

The Ruhr consists of a variety of subspaces with different sizes and population densities that are intertwined in complex ways with each other or separated by turning points of the infrastructure and their respective cores and connecting areas; therefore it has special urban qualities. This structure reveals a great potential as a framework for further development of the region into a grid-like structured metropolitan area with its own urban properties.

5.2.3. Bottrop

Bottrop is a city in west central Germany, on the Rhine-Herne Canal, in North Rhine-Westphalia. Located in the Ruhr industrial area, Bottrop adjoins Essen, Oberhausen, Gladbeck and Dorsten. The city had been a coal-mining and rail center and contains factories producing coal-tar derivatives, chemicals, textiles, and machinery. Bottrop grew as a mining center beginning in the 1860s, was chartered as a city in 1921, and bombed during the Oil Campaign of World War II. In 1975 it unified with the neighbor communities of Gladbeck and Kirchhellen, but Gladbeck left it in 1976, leading to Kirchhellen becoming a district of Bottrop as Bottrop-Kirchhellen.

Bottrop is divided into three boroughs, they are: Bottrop-Mitte (Bottrop-Center), Bottrop-Süd (Bottrop South) and Bottrop-Kirchhellen, each one having a borough representation and a borough ruler.

These boroughs are further subdivided into city parts, partly named after their traditional name, while the newly built parts are only recently named:

- Bottrop-Mitte: Eigen, Fuhlenbrock, Stadtmitte (City center)
- Bottrop-Süd: Batenbrock, Boy, Ebel, Lehmkuhle, Vonderort, Gartenstadt Welheim (Garden city Welheim) and Welheimer Mark

- Bottrop-Kirchhellen: Ekel, Feldhausen, Grafenwald, Hardinghausen, Holthausen, Im Loh, Kirchhellen, Kuhberg, Overhagen

The total area of the municipal territory is about 101 square kilometers. As of December 31, 2012, the population of Bottrop was 116,498 (Nordrhein-Westfalen 2011). Therefore the population density is 1158 citizens/km^2. Nearly 65% of the residential buildings in Bottrop are constructed before 1970. Only 5% have been built in the last ten years. The pilot area for the Innovation city Bottrop project has around 69,000 residents and 22,000 workplaces (Stadt Bottrop 2011).

The future action plans for this city are based on three main ideas:

- Development of an energy-independent district, Kirchhellen based on renewable energy and renewable resources, and the reduction of CO2 emissions in the same district by up to 100 percent by 2050
- Zero Emission: Maximum reduction of CO_2 emissions in pilot projects in all relevant fields
- InnovationCity Bottrop: integration of the objectives in the overall climate strategies of Bottrop with a major milestone: 2020; reduction of CO_2 emissions in the pilot area by 50% from the base year 2009

In 2009, renewable sources constituted 4% of the power consumptions of the Bottrop city. The vision of a medium-to long-term independence from fossil fuels to achieve power and heat supply from renewable energy sources, (therefore leading to the greatest possible reduction of CO_2 emissions in Bottrop) is a tremendous task, considering the mining industry dominated urban structures of the southern districts of Bottrop.

On the other hand, Kirchhellen is a predominantly rural suburban area with a large number of forests and farmlands. In this region it is possible to expand the existing infrastructures of renewable energy as well as the other regional networks, since there are suitable areas and locations for wind turbines, biogas plants, a large-scale geothermal project and a zero-emission industrial park. This endogenous potential yields correspondingly spatially differentiated models of climate protection concept for the entire city. The key objective for the district Kirchhellen is self-sufficiency in energy supply through renewable energy production by 2050. In addition, the CO_2 emissions of the district should in the long term be reduced to zero. These objectives require the extensive use of biomass, wind, solar and geothermal energy for power generation and a far-reaching improvement in building efficiency.

The policies Energy-autarkic Kirchhellen, Zero Emission and InnovationCity Bottrop complement each other in order to develop a sustainable climate strategy for the entire city. They cover both the rural areas (Energy-autarkic Kirchhellen), and the urban areas in Bottrop (Innovation City Bottrop).

The program activities and implementation strategies for InnovationCity Bottrop are coordinated with the objectives of the integrated climate protection concept. They complement each other to a very long overall approach to climate change.

Important steps in this development are to be taken, for example in promoting the production of electricity from renewable sources, which must be improved to reach the highest possible level. It should be noted that renewable energy could play an important strategic role in the issue of restructuring of the energy supply in closure of the mines in 2018, E.g. conversion of the land use of large scale sites for wind, solar, geothermal energy production.

In order to develop a sustainable strategy for climate adaptation throughout the city in Bottrop, the pilot area of InnovationCity Bottrop plays a very significant role. This area consists of high buildings and commercial and industrial structures forming an ideal combination of living, working and mobility.

A major part of the integrated climate protection concept with regards to the InnovationCity Bottrop, is the integration of different users and stakeholders, to mobilize and reinforce concepts of acceptance and willingness to participation.

Chapter 6: Analysis and Results I

6. Climate related features of Iranian Traditional Architecture and Urbanism

Urbanization and urban dwelling is one of the most important human achievements. Urbanization set off many social, cultural, industrial and economic transitions and thus led to the current lifestyles. Over ten thousand years ago, some of the Middle East residents found out that plants grow out of their seeds. This discovery was the basis for creation of new cities, empires and civilizations (Mohseni 1985).

In Iran, there are remains of urban life dating back to 5000 BC. The first cities were constructed at the submontane areas with fertile arable soil or near rivers with easy access to water for irrigation. Prehistoric urban settlements in Iran are evidences of this fact, such as *Sialk* in Kashan, *Gian* in Nahavand and *Shoush* in Khuzestan. The common feature of these cities in Iran and other areas in this period of time is the presence of a tall and strong fortification around the city.

In order to achieve a better understanding of traditional climate regulating elements of the built environment, the vernacular architecture and urban structures need to be studied in detail. There is an astonishing amount of literature present in this realm, mostly in Persian language.

First, Iranian cities in hot arid areas are discussed in their totality; Urban Street networks, urban texture, building size, form and orientation.

In the second part, structural components of these cities, mainly public spaces and public works, are discussed in detail. Afterwards, a traditional residential unit and its elements, local to this area, will be scrutinized in detail to provide a better recognition of the climate regulating approaches in a smaller scale.

In the end, the results of previous analyses of these structural components and their relationships will lead to a holistic evaluation of Iranian traditional architecture and urbanism, considering the harsh local climate and how it has adapted to it.

6.1. Urban formation

With the development of agriculture, specialization of professions and formation of local governments, rural agglomerations surrounded cities to provide products. In this period, cities played four major roles. They were the main location for the administrative bodies, non-agricultural affair, scientific and religious activities, and the main residential quarter for non-farmers (Gaube 1979).

These new life functions created the need for specialized urban spaces. The administration compound, which was called *Kohandej* before Islam and the *administrative Arg* after the introduction of Islam, was located in the heart of the city. Arg was in fact a highly fortified citadel, overlooking every district of the city. Although city dwellers were not directly involved in agricultural production, they mainly carried out marketing of these products. Therefore, vast commercial spaces were required in cities. Depending on the location and economical situation of the city, these commercial centers could be just a few small shops, or even grand bazaars, occupying up to one tenth of the urban area. Religious centers were the third distinct urban features. These centers were mostly constructed near the Kohandej and sometimes as a separate structure. Since most of the rulers considered themselves gods (pharaohs in Egypt), or delegates of god (Achaemenian and Sasanid kings of Iran), in some cases the administrative domicile and the religious center have merged into one complex. The largest urban spaces in terms of floor area were the residential districts. Citizens consisted of official workers, religious agents, artists, commercial and industrial business owners and their families. In eras, when the class system was in effect, citizen would reside in a specific district of the city according to their class and occupation (Ghobadian 2008).

6.2. Impacts of climate on evolution of cities:

Analyses of urban form in Iranian cities and villages in hot and arid area shows that climate is a major actor in the evolution of these cities. During the past centuries, people have tried to lessen the negative effects of this harsh climate, and improve their well being indoors. Climate has affected almost every aspect of human life: the way we build our houses, the way we commute in the public realm and even our diets. The dry and hot climate of the central Iran is visibly traceable in the principles of traditional Iranian architecture and urbanism. The main climatic features in this area are as follows (Tavassoli 2012, 99):

- Severe solar radiation
- Excessive heat
- Significant change in temperature during the day (hot days and cold nights)
- Significant difference in temperature during the year (Hot summers and cold winters)
- Low air humidity
- Minute precipitation and shortage of water
- Dust storms with occasional sand storm

The urban texture in these cities evolved in order to address these climatic conditions. They were generally dense and compact thus exposing the least amount of surface to solar radiation. A main characteristic of this type of urban fabric is dense, rather large urban blocks, mainly only one story high, with continuous roofs and narrow alleys in between. The light color of surface materials, mainly Kaahgel[17] also reflected the solar radiation back into the environment. Domes and arches were the main type of roof cover technique in this system of architecture. Thick outer walls and roofs absorbed diurnal heat and released this heat back into the environment during the nights, therefore minimizing the changes in temperature. Houses and public buildings were attached to each other; creating an integrated, secure mass. It is even argued that climate was the main reason behind the size of neighborhood units. Comfortable access to the public services in the neighborhood center, in this harsh climate, was a significant reason in limiting the size of neighborhoods and districts (Tavassoli 2012).

[17] Kaahgel is a mixture of clay and straws, used for covering building facades and as moisture insulation on roofs

The street network has also been affected by climate. The alleys and pathways are narrow and surrounded by high walls in order to maximize the shadow. In other words, the H/W ratio was very high. Some or all parts of these alleys were covered, either by arches (Posht Band, Figure 27) or by a series of arches and domes (Saabaat, Figure 26). In some cases, these arches were built as structural elements between the high walls, but in most cases they had another function as well. They provided shadow for the passersby and this semi-covered passage created a tunnel, which increased the wind speed, therefore improving thermal comfort. However, long straight alleys were avoided, in order to break down the wind speed (Ghobadian, Climatic Analysis of Iranian Traditional Buildings 2008)

Figure 26: Saabaat (Source: (Hamshahri 2013))

In some regions, Saabaat serves a third function as well; one of the adjacent units may extend above this roof, creating a space for a bedroom or storage area. Generally the street network consisted of short, narrow passageways, covered in some parts, zigzagging through dense built environment.

Figure 27: Posht Band (Source: (Tebyan 2011))

6.3. Urban centers and spaces

Every city, apart from its urban fabric, had a distinct center. The city center is a place where most of urban functions, such as commercial, political, religious and cultural functions, are concentrated there. Therefore, specific building and spaces such as bazaar and main mosques were located in the city center. One of the pronounced examples of city centers in Iran is the Naghsh-e Jahan Square in Isfahan, which possess all the properties of a typical Iranian city center. Similar to other urban spaces in the hot and arid areas, this square is pent in all directions (Figure 28).

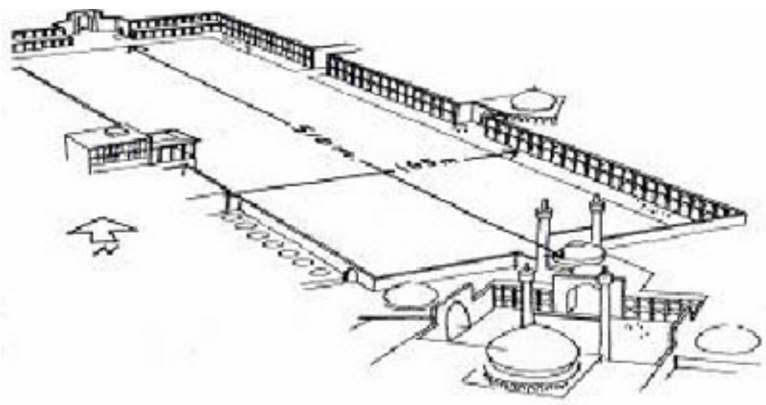

Figure 28: Naghsh-e Jahan Square

This square is limited to the bazaar in north, Imam mosque in south, Aliqapoo palace in west and Sheykh Lotfollah Mosque in east. The physical dimensions of this square are tailored to a large city and a vast empire; 510 m long and 165 m wide. Shops and bazaars surround this square. In order to provide a better ratio between the large size of the square and the rather low rising buildings around it, and to provide a better climatic condition, the second floor is equipped with a portico façade. Other urban squares that have a smaller scale and already exist today are the Arg Square in Tehran and the Ganjali Khan Square (Figure 29) in Kerman (Ghobadian 2004).

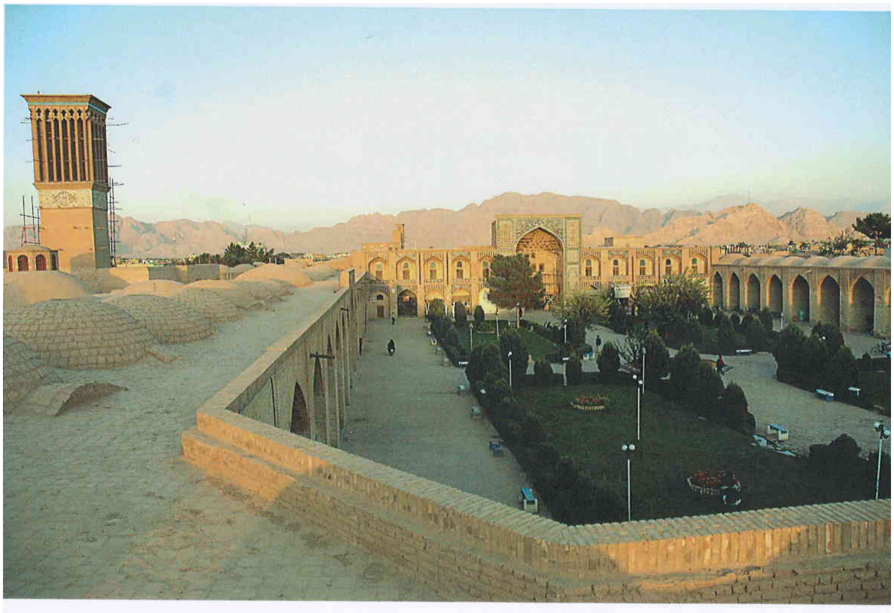

Figure 29: Ganjali Khan Square in Kerman (Source: (Sadeghi 2010))

6.4. Neighborhoods and neighborhood centers

Firstly, it should be noted that with the introduction of Islam to the Iranian culture, the social structure of the country was altered and the Sasanid era's social classes were not in effect any longer. This fact is highlighted in the physical structures of the cities as well. In the Islam era, every neighborhood was functioning as a distinct district as a part of a larger city, and possessed its unique identity and specifications. Neighborhood identity was of great significance and value, and every neighborhood tried to demonstrate their specific trends in the neighborhood center, especially with the religious celebrations.

Neighborhood centers functioned similar to the city center, but on a smaller scale. These centers, typically consisted of a square, one or more mosques around it, a roofed or roofless Hussainia[18], one or more grocery shops for local residents, a public bath, and in larger neighborhoods an Ab-anbar, a Madrasah and a Caravanserai.

6.5. Bazaar and commercial structures

As the concentration center of political, cultural, commercial and service activities, cities needed physical structures to facilitate these functions. Urbanization was not only the concentration of urban dwellings, but also the development of other public and private urban buildings. Bazaar and other commercial buildings played an important role in the Iranian cities of the Islamic era (Ghobadian 2008).

A few centuries after the introduction of Islam, commercial situation recovered and bazaars were developed in cities as an important urban feature. These primitive bazaars turned out as models and bases for future bazaars. In smaller cities, bazaar consisted of a few shops in the city center and in larger cities, where bazaar had a key role in the economy of the region and the country; it was composed of several hundred shops. Bazaars were the walkable infrastructures of the city, surrounded by many support structures, such as passages, mosques, ab-anbars and public baths.

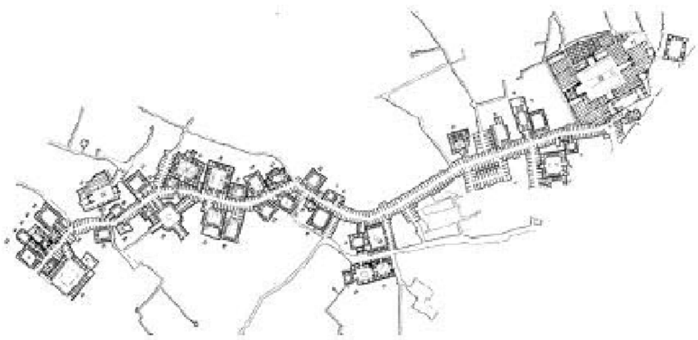

Figure 30: Bazaar of Isfahan and its surrounding spaces (Source: Masoudi Nejad 2005)

According to their role as the center of social, cultural, political and religious activities, bazaars have been compared to piazzas of Middle Ages European cities and Hiroba in Japanese cities. The bazaar is the center of the spatial system of Iranian cities. It is usually formed in a linear form and public and socio-cultural spaces are organized through this linear form (Figure 30). Karimi's spatial analyses (Karimi 1997) of six Iranian cities by axial modeling are a clear proof of this point. His studies show that the most integrated part of

[18] A Hussainia is a congregation hall for Shia commemoration ceremonies, especially those associated with the Remembrance of Muharram.

spatial structure is located in bazaar, which proves the bazaar to be the core of spatial structure of cities and therefore the destination of all main routes.

Figure 31: The Global Integration (Rn) map of Kerman (Source: Karimi 1997)

Reza Masoudi Nejad has done an extensive analysis on spatial configuration of bazaars. He argues that the Iranian cities before the Modernization can be categorized in two types, based on the idea of bazaar. The first city type consists of cities with non-merchant economy. In this city type, bazaar is a purely retail cluster and it does not include other socio-cultural spaces, like the bazaar of Dizfoul and Shushtar. He calls this type "*Commercial bazaars*". Using Space Syntax through the axial analysis he shows that "Commercial bazaars" not only were not the most integrated part of the city structure but also were not the centre of social activities. The second city type includes cities with bazaar-based economy. Bazaar in this type of cities is the centre of the social and economical activities of cities. Therefore it is called "*Socio-commercial bazaar*".

6.5.1. Bazaars in hot and arid climate

In this climate, masonry arches covered most of bazaar stretches. Because of bioclimatic issues, namely high air temperature and solar radiation, the arches are high, with holes on top of them to allow ventilation. The bazaar stretches are also rather wide. In some bazaars, such as the Vakil bazaar in Shiraz or the Ibrahim Khan Qeysaria in Kerman, apart from the vent holes on top of the roof, there is a series of openings under vaults, providing ventilation and lighting (Figure 32).

Figure 32: Openings in the vertical partition (Credits: Bahram Ardabili)

These arches and domes acted as heat capacitors. Not only did they block the excessive solar radiation in summer, but also they regulated the internal air temperature during nights and winter period. Moreover, they created safe and comfortable environment in face of desert winds and dust storms. In recent years, it has been noted that these arches also block the noises of motor traffic and industrial workshops.

Typically, when the bazaar stretch meets a specific structure, i.e. a mosque or a bath, the height and width of the stretch is increased. To cover this section, commonly a high dome is constructed, under which Iranian-Islamic ornaments are visible. Charsouq is the junction where two stretches of bazaar cross over each other (Figure 33).

Figure 33: Under the dome of Charsouq in Kerman (Source: (Parsi Patogh Foundation 2011))

In bazaars in hot and arid climates, the width of shops is usually equal to the free distance between the bases of consequent arches, which never exceed three to four meters (Figure 34). Some shops also have under ground sections, which is mainly used as storage area.

Figure 34: Bazaar -e Qalle (Source: (Tebyan 2011))

The height of the arches of each bazaar stretch depends on its commercial and economic significance; in important stretches, i.e. Qeysarias or sections of bazaar where valuables were traded, the arches are higher than the rest of the bazaar (Figure 35). The Safavid era Bazaarche Shahi in Isfahan, which was a specialized market for trading gold, is a good example of this fact.

Figure 35: Section of an important part of Bazaar with higher roof (Source: (Tebyan 2011))

The construction of bazaar complexes took a long time and typically every ruler of the city would add a new section to the bazaar. The sections ordered by politically or religiously significant people were usually designed with a higher roof. The best construction materials were also used in the development of these sections.

Shopping in hot and dry condition is not desirable for anybody. The arched roofs, not only provided a secure shaded place for shoppers and merchants, but also they created a meeting point with human scales. The existence of roofs was also an effective factor in the value of the shops in bazaar. In the roofless section of bazaar the real estate values were lower and cheaper products such as vegetables and fruits were traded.

6.5.2. Saraa, Tim, and Timche in bazaar

One of the peripheral structures of bazaar is Saraa. Saraas were located next to the main stretch of bazaar and their physical plan was similar to most caravanserai structures with a central courtyard. The courtyards of caravanserai and Saraas are the only locations in the bazaar complex with plants and water pools, and play an important role in subtilizing the environment.

Although Saraas and caravanserais are similar in their physical structure, they had two different functions. Caravanserais provided accommodation for the caravans of merchants visiting the city, while Saraas were commercial centers. Therefore, there is no stable in the Saraas; instead peripheral spaces are assigned as storage areas. Moreover, due to limited land and high real estate value in bazaars, Saraas were designed in two floors. Unlike caravanserais that are separate and independent structures, Saraas are incorporated in the bazaar complex, both in function and fabric.

Tim and Timche had similar function and structure as Saraa. Dehkhoda defines them, as “Tim is a large caravanserai, while Timche is a small one”. Tim, Timche and Saraas were safe places in bazaar and the caretaker locked them down at nights. The main difference between these is the presence of domes. Whilst Saraas have no domes or arches, there are one or more high arches in the central courtyards of Tim and Timche. As these domes were not visible from outside, their outside appearance was not developed that much. However, a great deal of effort has been put in designing the inside of the domes with intricate ornaments. The domes of the Grand Tim in Qom (Figure 36) and Aminol Dole Timche in Kashan (Figure 37) are good examples of these ornamental designs.

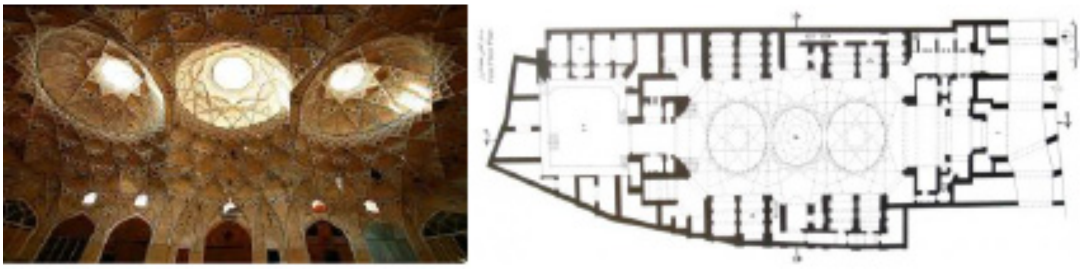

Figure 36: The Grand Tim in Qom Bazaar (Source: (Faculty Members 1999))

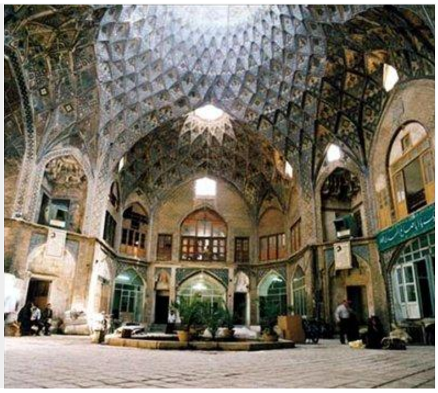

Figure 37: Aminol Dole Timche in Kashan Bazaar (Source: (Iranian Virtual City 2009))

6.6. Religious buildings

The remains of religious buildings date as back as the beginning of civilization. With the intrusion of Muslims into Iran, the first buildings that they developed in the occupied cities were mosques. These structures were typically constructed in central and focal points of the city, and in some cases over the Zoroastrian temples. Arabs did not have a unique and specific architectural style and constructed the first mosques using primitive construction materials, such as clay adobe. Later on, when the Umayyad Caliphate was established in Syria, the form and fabric of mosques were improved and the advanced architectural technics of the occupied lands, i.e. Eastern Rome and Sassanid Iran, were used in mosques.

6.6.1. Mosques in hot and dry climate

The first plans of the Iranian mosques consisted of a central courtyard, a Shabestan[19] towards Kiblah and porticos on the other sides (Figure 38). These porticos were typically built of brick columns and arches. Although the physical plan of these mosques is similar to the Arabic mosques, but the type of the arches and the brick laying techniques are those of Sassanid era. However, this style did not last for a long time and after the sixth Hijri century, the four-Iwan

[19] A Shabestan is a space that can be usually found in traditional architecture of mosques and schools in ancient Persia (Iran). These spaces were usually used during summers and could be ventilated by windcatchers and Qanats. They were roofed spaces with rows of parallel columns.

style of mosques was the most common. However, in the Arabic countries, the primary style is still in use, even today.

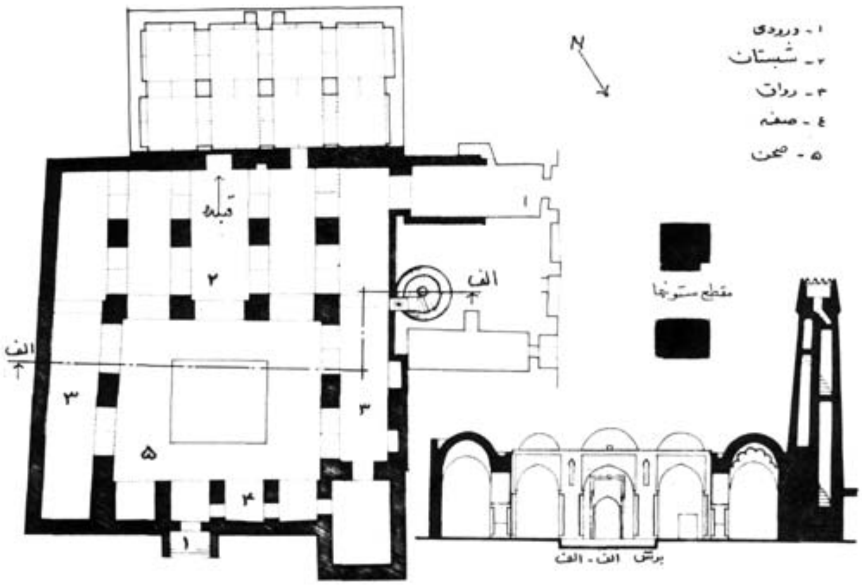

Figure 38: Plan and section view of Fahraj Friday Mosque (Source: Personal Archive)

An important factor in the design of the mosques is the orientation of the building, which is towards the Kiblah, instead of being a function of the direction of wind and solar radiation. The location of Mihrab[20] as a focal point on the main axis, symmetry in plan and section and the segregation of the internal and external spaces of the building are also noteworthy. The Jame mosques of the cities, as symbols of urban, cultural and political identity, were typically one of the tallest, most beautiful and in some cases largest buildings of the city. Therefore, climatic conditions were not the only effective factor in the design of these mosques and religious and political motivations were more effective. However, in the four climates of Iran, the fabric of the mosque has been adapted to the local climate, to provide thermal comfort for the visitors.

In the Iranian plateau, because of the high temperature in summer and high fluctuation of temperature between day and night, the following principles have been observed to create a comfortable environment within mosques:

a) Central courtyard is the most significant structural element of the mosques in hot and dry area of Iran. The presence of water pool and splashing of water on the courtyard surface is effective in regulating the microclimate of the inner areas.

[20] Mihrab is a semicircular niche in the wall of a mosque that indicates the Kiblah.

b) The bulk of the building, as a piece of the rest of the urban fabric, is integrated with the peripheral structures, decreasing the effect of the fluctuating outside temperatures on the inside climate. Massive thermal mass of the interconnected buildings is the reason behind this phenomenon.
c) In this region, the main construction materials of the mosques were bricks and adobes. In areas with easy access to mountains, stones were also incorporated in the bulk of the mosque, especially in the foundations. Because of the high density of these materials and the high diameter of the buildings tissue, not only did they act as a thermal capacitor, but also they were playing the role of thermal insulations.
d) To provide thermal comfort, the roof height was relatively high and there were more openings in comparison to the mosques in other regions.
e) Next to the main mosques of this area, there is a winter Shabestan with lower roof height, suitable for religious activities during the cold season
f) In some mosques, especially around the central desert of Iran, there is an underground section, where religious activities take place when the outside temperature is too extreme.
g) Windcatchers have been added to some of the mosques to provide ventilation and cool the spaces, i.e. Jame Mosque of Firozabad, Aqa Mosque in Kashan, Imam Mosque in Tehran. In some mosques, the windcatcher is directly above the Mihrab, and in some of them it is located on the top of Shabestan.
h) Ab-anbar as a public utility structure is located next to or below the courtyard to provide cool water to the visitors year-round; i.e. Jame Mosque of Naeen and Jame Mosque of Ardestan.

Although in other climate regions of Iran, mosques were also developed with central courtyards, in this region the courtyard was typically larger and more significant. These courtyards had axial symmetry in relation to the Mihrab and were surrounded by four high Iwans, a design pattern that was copied by other Muslim nations in the following centuries. These mosques were common in Iran after the 6th century and are known as the Iranian style mosques (Figure 39). It should be noted that Iwans, concerning the lighting, ventilation, temperature and visibility, create an environment between the outside and the inside and provide a comfortable thermal situation especially for the afternoon hours.

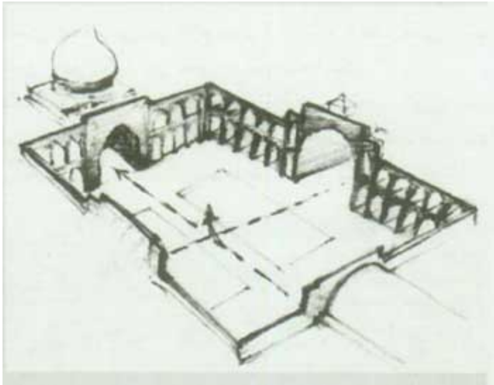

Figure 39: Four Iwan courtyard structure (Source: Ahmad Hosseinzadeh)

One of the largest and oldest central-courtyard mosques of Iran is the Friday Mosque (Atigh Jame Mosque) of Isfahan (Figure 40). Because of its location in a significant city and its size, it has always attracted the attention of rulers. Therefore, since its construction in the second Hijri century until recently, new sections have been added to it and the older parts were renovated.

Figure 40: Courtyard of Isfahan Friday Mosque (Source: (Roghayeh 2012))

Regarding the climatic situation, the Friday Mosque of Isfahan is a good example in the hot and dry climate of Iran, which has established suitable thermal comfort for the visitors. In summer, when the temperature reaches as high as 40°C, Muslims pray under the high dome or in Iwans and Shabestan. In all these spaces, human thermal comfort is met by the shade of arches and domes, draught by the high openings and vertical ventilation (Figure 41). Moreover, high thermal mass of the mosque bulk, regulate temperature fluctuation over day and night. A common practice is to splash water on the courtyard surface, which settles dust and reduces the air temperature of the courtyard and peripheral spaces through evaporation. In spring and autumn, air temperature in Isfahan is close to the range of human thermal comfort and Muslims can carry out their religious practices without any discomfort. In these seasons, thermal mass of the mosque also regulates the temperature and saves the diurnal heat for colder nights.

Figure 41: Shabestan at the Friday Mosque of Isfahan (Source: (Roghayeh 2012))

In the end of autumn and during winter, when the weather is colder, the winter Shabestan behind the western Iwan is used (Figure 42). This Shabestan is entirely enclosed and has a low roof, making it easier to warm it to create desirable thermal situation for religious activities in winter. Although thick walls and columns provide higher thermal mass, they occupy a lot of space, making it more difficult to hold large masses and gatherings. The presence of 477 arches and domes in this mosque with different techniques and styles is a symbol of the gusto and creativity of the Iranian masons and architects in previous decades.

Figure 42: Winter Shabestan at the Friday Mosque of Isfahan (Source: (Arianica Foundation 2010))

6.6.2. Madrasa

Madrasas in Iran are considered as religious structures. Renowned madrasas in the Islamic era were typically located next to the main stretches of bazaar or main mosque of the city. Madrasas date back to before Islam and it is argued that with the formation of official departments, madrasas were developed to teach the academic sciences to future administrators. The first signs of madrasas are found in Susa of the Elam era. Academy of Gondishapur in Khuzestan was considered a significant madrasa, famous for its programs in philosophy and medicine. With the introduction of Islam and formation of Samanid, Buyid and Seljuq dynasties, madrasas gained much more attention, and Iran became a center for knowledge and science.

Formation of Madrasas in hot and dry climate

Similar to other traditional structures in Iran, madrasas were designed in a way to take full advantage of the climatic situations in order to provide suitable human thermal comfort in all seasons. Moreover, the physical plans of madrasas were devised in such a way to facilitate its main function, nurturing jurists and scholars in an environment proper for debate. There were two types of madrasas in Iran; the first type was a part of a mosque complex, where the functions of a mosque and a madrasa had been integrated, and the second type was an autonomous educational unit, where students resided and studied.

The most significant structural component of madrasas, similar to mosques of the plateau, is the central courtyard, especially courtyard with four Iwans. The use of this style in madrasas was common 50 years before its introduction to the mosque design. The entrance to the building is an Iwan with a high dome or arch. Other Iwans were used as educational spaces and in some cases library. Secondary functions of the structure, i.e. toilets were behind the residential areas or at the corners of the courtyard.

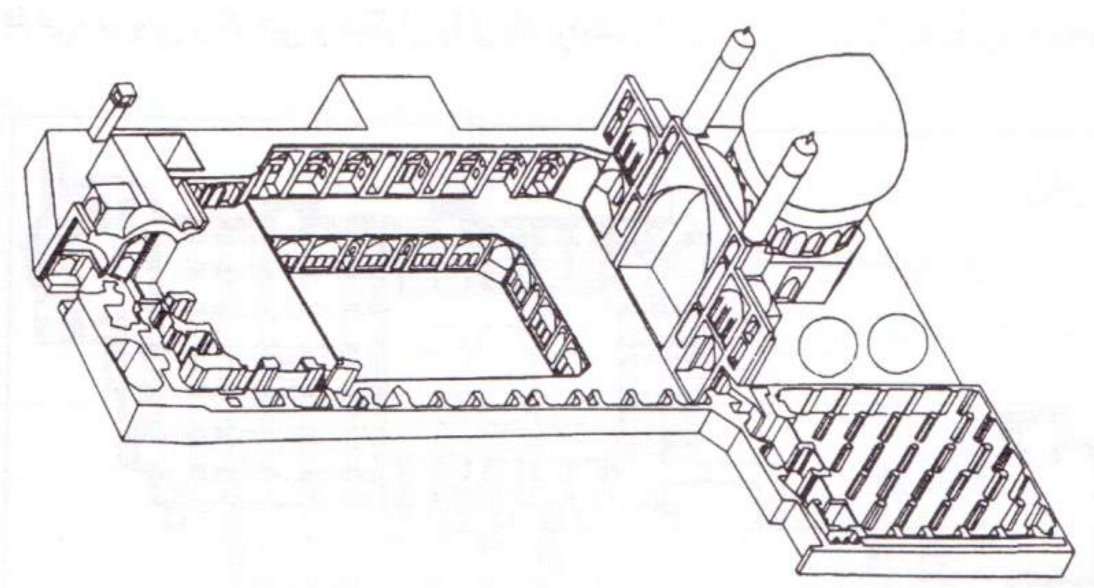

Figure 43: Perspective of Aqa Bozorg Madrasa in Kashan (Source: Personal Archives)

As mentioned before, some of the madrasas were merged with mosques and one typical example of this madrasa is the mosque and madrasa of Aqa Bozorg in Kashan. This madrasa complex that was built in Qajar era is a true masterpiece of Iranian climate-friendly architecture.

In order to separate the two functions, the central courtyard was constructed in two stories (Figure 44). The bottom level is dedicated to madrasa, with the student residential cubicles around it. Similar to other courtyards in this climate, there are water pools and vegetation in this courtyard that play a major role in regulating the microclimate. In mosques, the water pools were used to perform Wudu, the Islamic procedure of washing parts of body, in preparation for formal prayers. South of the ground floor courtyard, is the dome house, which is open in four directions because of the hot and dry climate of Kashan. Therefore, in hot summers of Kashan, with the shade and draught of the dome house, visitors experienced a comfortable thermal situation. However, the old mosque, which is located under ground to the north, is used in thermal extremes. This old mosque is equipped with two windcatchers for ventilation and today it is used as a library.

Figure 44: Aqa Bozorg Mosque and Madrasa Complex in Kashan (Source: (Roghayeh 2012))

West of the dome house, the winter Shabestan is located, with enclosed spaces and low roof, typically used in cold months of the year to perform religious activities. In the south, there are two courtyards, one at the same level with the dome house, and the other, similar to the madrasa courtyard in a lower level. An Ab-anbar is present here as well to provide cool water to the visitors.

Although the design and construction of this mosque-madrasa was not performed in one single step, in every stage it has been done with full consideration of the local climate, creating a structure, which enabled the performance of its designated functions in an acceptable thermal comfort situation in all seasons of the year.

6.6.3. Meydan, Tekyeh and Hussainia

An inseparable part of the physical fabric of Iranian cities is the space dedicated to the religious activities of Muharram month, celebrating the martyrdom of the 3rd Imam of Shias. The religious function of Meydan, Tekyeh and Hussainia is rather similar, so are the festivities celebrated in them. Depending on the region, this space is called by one of these names; however, in some cities around the central desert it is often called Meydan (square), because they had other urban functions as well.

Formation of Hussainia in hot and dry climate

In the Iranian central plateau, especially in cities around the central desert, Hussainia is completely integrated into the cultural and social fabric of the neighborhood and city, both regarding its form and its physical fabric. In these cities, a Hussainia is a space in the center of the neighborhood where gatherings and social activities take place. The so-called spaces are mostly enclosed, symmetrical and in form of a rectangle or an octagon. Since these spaces are closed off, they offer a rather regulated thermal situation in this hot and dry region.

In order to create sitting space for the audience, the wall around Hussainia is constructed in two stories, with steps as sitting area. False arches are often seen on these thick walls to create a visual rhythm. In some Hussainias, i.e. Amir Chakhmaq in Yazd, the wall towards kiblah is of great significance and is designed in a stepping fashion. In Amir Chakhmaq, there are two high rising minarets in one side of the Hussainia, which are considered one of the highest minarets of the city. In this Hussainia, which is the main Hussainia of Yazd, only the wall towards kiblah, the bazaar behind it and a portion of the western wall has remained. Due to the ignorance and listlessness of urban designers and officials, the rest of this valuable urban space has been turned into parking areas.

In the old fabric of Zavareh in Isfahan province, two main spaces exist, called the grand Hussainia and the small Hussainia (Figure 45). These two are located in the urban core of the city; next to the bazaar and the Jame Mosque, directly connected to the main passageways, and are designed to perform the mourning celebrations in the best way. The unroofed and rectangular space of the Hussainia, which is dedicated to the activities in the warm season, is symmetrical.

Figure 45: The Grand Hussainia of Zavareh (Source: panoramio.com)

The brick double-story enclosure around these Hussainias protects the visitors against the harsh environmental situation of the desert. In cold months of the year, roofed spaces in the vicinity of Hussainias are used for religious festivals.

6.7. Public Baths

Public baths were also significant urban structures, typically located in the neighborhood center or in the vicinity of bazaar stretches. From the pre-Islamic era, signs of private baths have been found in the ruins of Persepolis (Achaemenid Empire) and Ashour Palace (Parthian Empire). However, before the introduction of modern urban piping systems, public baths were common in Iranian cities.

Since the process of bathing has several stages, the Iranian traditional baths had distinct spaces, dedicated to a certain function. The inner spaces of a Hammam (bath) can be divided into three main areas: Semi warm and moist, warm and moist, very warm and moist. The inner climate was regulated in a way that humidity and air temperature would increase from the entrance towards the central spaces. Therefore, these spaces are completely separated, only connected indirectly through narrow corridors (Figure 46). This fact is present in baths of all Islamic periods and in every climate.

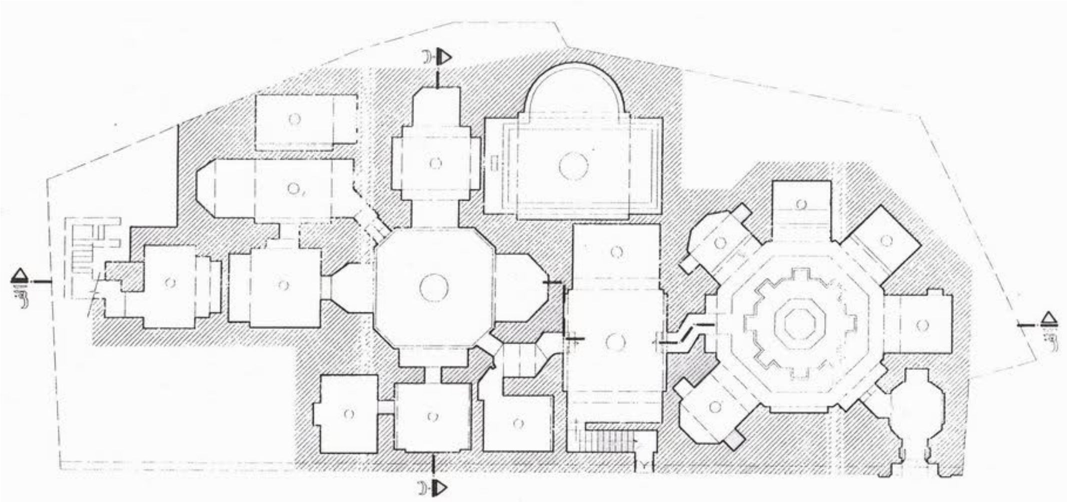

Figure 46: Qajar Hammam in Qazvin (source: Mirzaie, E.)

6.7.1. Baths in hot and dry climate

Since Hammam is an enclosed space with minute connection to its environment, the physical structure of them is rather similar all around Iran, and climatic elements, such as wind, solar radiation and geographic location play no important role on their formation. However, in hot and dry climate, in order to keep the inner temperature stable, baths were constructed in the ground. The building materials used in the construction of Hammams were always durable and the roofs of the major baths were in form of domes or arches. However, in mountainous areas, flat timber beams roofed the baths.

While the microclimate of the bath is completely separated from the outside environment, in every part of it, temperature, humidity, light and ventilation had been regulated in accordance to the functions. Therefore, bath design and construction relied heavily on bioclimatic techniques to provide suitable thermal conditions for visitors around the year.

Heat

In that time, the main source of heat was the burning of fossil fuels, which created smoke and poisonous gases. Therefore, the heat required by Hammam had to be generated outside. In this Fire Chamber, fire would heat up the boilers and smokes were directed outside through a set of underground channels below Hammam. This would act as under-floor heating, warming the inner areas. These channels were covered by marble stones, which maximize heat transmission and are easy to clean and maintain. The Fire Chamber was connected to the main passageway to bring in fuels.

As mentioned before, Hammams were often constructed into the ground, so their ground level was below the street level (Figure 47). The soil surrounding the walls would act as insulation, minimizing the heat flow. The massive bulk of the structure also performed as a thermal capacitor, regulating temperature fluctuations. Another advantage of lowering the bath level was the possibility of channeling water into the bath. However, in areas with high ground water level, Hammams had to be constructed on the ground level.

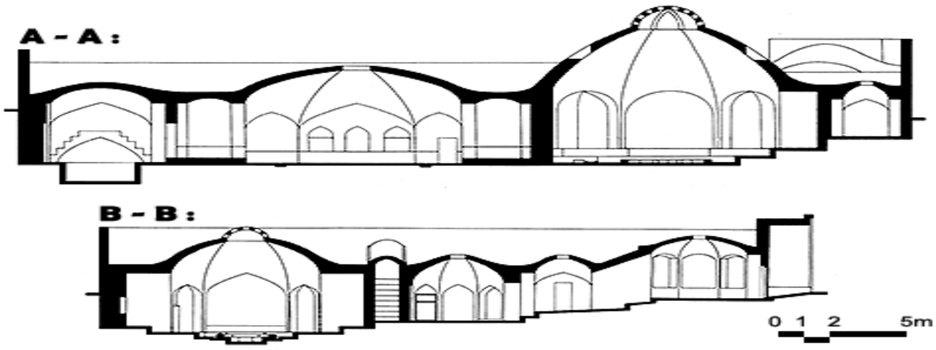

Figure 47: Section of a public bath (Source: (Ghoolabad 2010))

Water and moisture

The required water was obtained from ponds, Qanats or water wells. Ceramic pipes were used to transfer water to the main tank. Next to the Garmkhane[21], in some larger and more luxurious baths, there was an unheated pool used for swimming in summer. There were also other smaller water pools in other parts of the Hammam, which were used by the visitors for bathing. There was a gradual increase in air temperature and humidity, from the entrance of the bath towards its core.

[21] Heated areas in a bath

Figure 48: First Hall of Ganjali Khan Bath in Kerman (Source: (Alfaee 2009))

Ventilation

Creating a suitable environment for bathing, apart from regulating temperature, humidity and light, required providing enough ventilation as well. Presence of many visitors, high humidity and use of oil lamp exacerbated this need.

Hammams were ventilated through the openings under their domes (Figure 48). Moreover, they followed specific practices in using the oil lamps in Hammam area to lower their negative effect.

Materials

Since public baths were designed to service generations, durable materials were used in their construction. Walls and arches were often made of brick. Up to 2 meters of the walls were tiled from the floor level and a mixture of quicklime covered the rest. Unlike mosques and madrasas, human and animal figures are used in the ornaments of Hammams, along with some arabesque patterns.

6.8. Ab-anbar

Because of the dry climate in Iran, total lack of precipitation in at least 6 months of the year and seasonality of rivers, different strategies have been adopted to provide drinking water in the dry seasons. Construction of dams, Qanats and Ab-anbars are examples of these strategies. Ab-anbar, literally translated as the water storage, was used to store water in seasons with precipitation for use in the rest of the year.

Similar to other urban structures in the Islamic era, Ab-anbars were constructed in gathering centers such as bazaar stretches, neighborhood centers and caravanserais. In Iranian cities with hot and dry climate, typically every neighborhood had its own Ab-anbar, constructed by the local residents. No one was charged for using this water infrastructure, and wealthy residents of the neighborhood would pay for the repair and maintenance of Ab-anbar. Ab-anbars, with their high rising wind catchers and grand domes, were a significant player in the skyline of these Iranian cities. Furthermore, the main ab-anbars of each city were usually ornamented with Muqarnas.

Ab-anbars consisted of a large square or cylindrical reservoir in the ground, a domed roof over it and one or two lines of steps to access the water output area (Figure 49).

Figure 49: Stairway and windcatchers of an Ab-anbar in Yazd (Source: (Alfaee 2009))

Water

The storage basin was typically rinsed at the end of winter, and later on, in the beginning of spring, it was filled by streams and Qanats. A crucial element in locating ab-anbars was easy access to running water in wet season. The water stored in ab-anbars was cool and perfectly suitable for drinking, and it was only used for human consumption. Three mechanisms were adopted in providing drinkable water year round; first, the storage was kept in utter darkness and anaerobic organisms could not grow. Secondly, the earth gravity would cause particles in water to sediment. Thirdly, salt and lime were spread over water for disinfection.

The water tap was typically one meter above the storage bottom level to avoid the sediments. Since the storage basin was deep in the ground, the water was kept cool during summer days and it would not freeze in cold wintertime (Figure 50).

Ventilation

The storage basin in all of ab-anbars is ventilated to keep the water cool and reduce the humidity to avoid damage to the structure. Therefore, ab-anbars have either openings on their roof or windcatchers. The flow of air through these openings increases water evaporation, hence cooling the space within Ab-anbar.

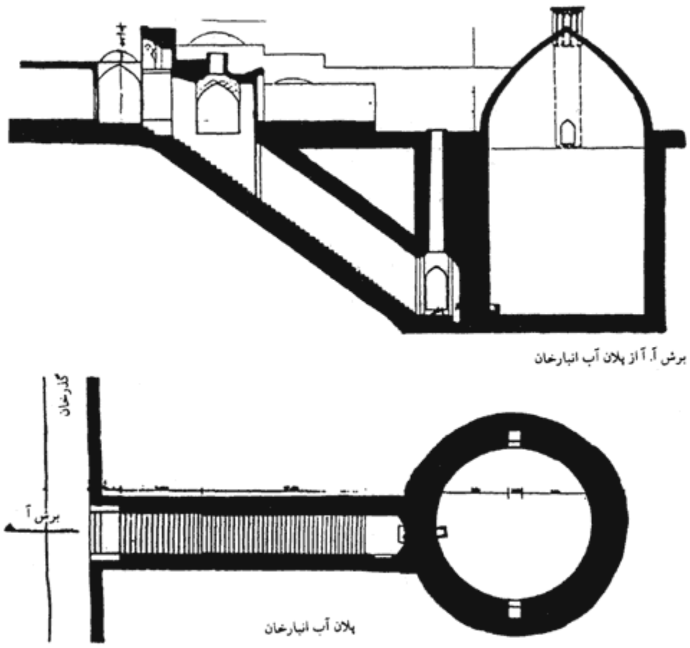

Figure 50: Section and plan view of Khan Ab-anbar (Source: (Ghoolabad 2010))

Grounds

A land plot would be chosen for Ab-anbar, which had a rather dense soil type that could bear the heavy weight of water and the Ab-anbar support structure. In order to lower tension on the walls, the storage basins were constructed under the ground level, where soil behind the walls would act as a support system. Moreover, in case of an earthquake, this structure would be more tolerant against lateral forces. Additionally, when the basin is lower than the ground level, stream water can be directed in to it easily. When the basin is 5-6 meters below the surface, the temperature fluctuations would be minimalized.

Materials and construction of Ab-anbar

After determining the location of Ab-anbar and digging the ditch according to the designs, the bottom would be covered with a lime concrete. In some cases, the floor area of the basin would be covered with a layer of lead and then bricks (Figure 51). A specific type of bricks, which was durable against humidity, was used in the construction of the walls. Afterwards, the walls and the floors were covered with a plaster of lime and ashes, and later arches and domes were erected to cover the complex.

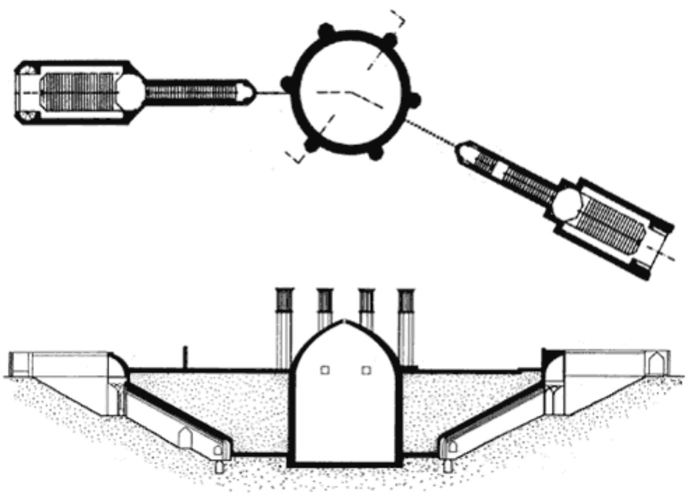

Figure 51: Section and plan view of an Ab-anbar in Yazd with 6 windcatchers (Source: (Ghoolabad 2010))

Access stairway was usually parallel or perpendicular to one of the sides of the tank and would connect the water tap area to the outside world. At the end of this stairway, one or more brass taps were embedded. In most cases, the roof would keep its spherical form, but in situations where the rooftop had to be used or in ab-anbars mixed with other structures, such as mosque or madrasa, the spherical roof would be morphed into a flat roof, using a series of smaller arches.

Although Ab-anbars were often considered as public infrastructure, some wealthy citizens of the cities in hot and dry climate had a private Ab-anbar in their residence. Typically, an underground room was devoted to water storage, which similar to public Ab-anbars would be cleaned and refilled with streaming water every spring.

6.9. Residential Architecture

Housing is one of the main features of Iranian traditional architecture, which is less discussed. When the prehistoric man moved out of the caves, they needed shelter against the environment; therefore construction of a house was the first stage of architecture. When man comes to the moor, he constructs something similar to the cave.

Archeological investigations by Dr. Negahban and Dr. Malekzadeh have demonstrated remains of an ancient human settlement near Buin Zahra, dating back to 6000 years BC. These residences were designed to meet the requirements of the time. In those days, clay was set to dry up in sun, instead of baking in an oven. Regarding the location of this settlement, wood was used for roof covers and the spans were generally narrow. There was even logic behind the design of the passage network. However, the most significant fact about these primitive houses is their introvert style, as there were no garden or vegetation outside. Kiosk-style buildings that were developed later in gardens, have visual access to the surrounding garden, however, even there, a wall is enclosing the whole complex.

This aspect of Iranian architecture is in accordance with the Iranian culture. The inner core of the house, where the wife and the children resided had to be diverse to avoid boredom. Even during the Qajar era, when Iranian architecture was declining, there were many astonishing houses designed. Nevertheless, this style had problems too, i.e. the toilets were far away from the residential spaces or using the kitchen was difficult in winter. Yet, cultural aspects explain why the space was structured in that way; the toilets had to be away from the living area and the kitchen was a place, where the lady could work in freedom, without being seen by strangers.

Before focusing on the structural components of an Iranian house, an introduction on the formation of houses within cities is necessary. The orientation of the structures, traditionally known as Roon, depended on the climatic conditions mainly wind direction, solar pattern, location of the building and the soil type. Three main Roons were common in Iran; Straight Roon (Roon Raste), Isfahan Roon and Kerman Roon.

In Straight Roon, buildings where oriented in Northeast-southwest direction. This Roon is used in central cities such as Tehran, Yazd, Jahrom and in Tabriz, in northwest of Iran. This orientation is almost perpendicular to the direction of kiblah.

Isfahan Roon is directed in Northwest-southeast and is adopted in Isfahan, Estakhr and Persepolis. Kerman Roon is oriented in East-west direction to avoid the Black Storm[22]. The same orientation is used in Hamadan too. Because of the presence of two mountain ranges near the city, if the buildings were oriented towards north, cool breezes would raise problems in daily life.

Kerman Roon is not suitable for Yazd, since it is cold in winter and hot in summer. Sadly, this fact has been neglected in the recent development in this city. Even in Tehran, bad orientation has led to serious problems, i.e. air stagnation in the western parts of the city. Generally speaking, Roon is of significant importance and needs to be studies in more detail.

Panaam is another important aspect of Iranian traditional housing. Literally, Panaam means an insulation or barrier, which blocks the displacement of something. In Iranian traditional architecture, all the roofs, regardless of them being flat or spherical, were constructed in two separate layers. This not only led to a lighter roof, but also decreased heat transfer between outside and inside environments.

Vertical and horizontal Panaam structures were adopted according to the Roon, solar pattern and other environmental variables. Tabeshband or Aftabshekan are partitions around openings, 6 to 15 cm wide, rising as high as 5 meters and were made of gypsum and cane. Orsi was a sash developed to block heat. This element was modified through time and a semi circular or square component was added above it. Sedaris[23] were also designed in a way that direct sunlight could not penetrate into them. Rooftop lighting was another technique of blocking sunlight. Moreover, there were no openings in the western wall to avoid afternoon sunlight; hence spaces behind this wall were lighted through the roof.

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[22] A Black Storm is a sudden dust storm common in Iranian desert cities.
[23] Rooms with three sashes

Figure 52: Sedari in Laariha house (Source: panoramio.com)

The main elements of a residential house in the central regions of Iran were entrance, Hashti (porch), Rahro (corridor), Hayat or Mianserai (courtyard) and rooms (M. Pirnia 2005).

In Iranian central cities, any opening in the walls is equal to the intrusion of sand and dust into the house. Even today, with the introduction of modern construction materials, sand is a problem for urban dwellers, and even under normal conditions, a thin layer of dust covers everything. Moreover, because of the hot and dry climate, the outside environment lacks attractive features, i.e. vegetation, therefore the visual connection to the outside is not that important. Instead, this visual attention has been moved to the inner core of the house, especially the courtyard.

Connection and harmony with nature, similar to other regions of Iran, has led to the notion of intramigration. The residential spaces were divided into summer and winter areas. During summers, spaces such as the basement, Talar and Hozkhaneh were used, while other areas such as Tehrani, Sedari, Panjdari and Balakhaneh were occupied during winter. The summer section was located on the southern part of the building to avoid sunlight, while the winter section was on the opposite part to allow sunlight. Because of the western afternoon light, false arches, small Iwans or secondary service space, often occupied the eastern side of the courtyard.

Figure 53: Windcatchers in the skyline of Yazd (Source: Albert Videt)

Badgir or windcatchers were one of the most significant techniques of dealing with the environment that was adopted in central desert cities of Iran. This important and elegant component, redirected the wind into the house, cooling the internal environment (Figure 53). As mentioned before, apart from the climatic factors, cultural beliefs were also effective factors in the configuration of spaces within an Iranian house. The internal spaces (private areas) were separated from external spaces (public and semipublic areas), through innovative mechanisms.

Division of the house into summer and winter residence and the seasonal internal migration was performed in various ways. In the first type, the winter-summer intramigration happened in one side of the building, while in the second type this migration was carried out in two opposite sides of the house. Iwan played an important role in the space configuration of both types.

In some regions of the central desert of Iran, such as Ardakan and Meybod, windcatchers are mono-directional. They channel the favorable north wind, and a wind current known as Isfahan, into the house, while blocking the hostile wind currents. Moreover, traditional houses in Meybod have another specific feature as well. Meybod has both compact and dispersed urban fabric. In the compact area, houses have been built on a small scale, sometimes with a Godal-Baqche[24]. The main trait of these houses is the location of the winter and summer spaces on one side of the building. In the dispersed part of the city, houses are larger and greener and the spaces are located on both sides of the courtyard.

[24] Godal-Baqche is a green area in the middle of the central courtyard, with a floor level lower than that of the courtyard

6.9.1. Characteristics of residential spaces

Architects of Iranian desert cities used various elements in developing these human settlements. Historically speaking, each of these components is of great value. Some of these elements are described in the following, such as Talar, windcatcher, entrance, courtyard, rooms, Hozkhaneh, basement and Payab (Memarian 2005).

Figure 54: Talar and Windcatcher of Laariha House (Source: Shabnam Sarboni)

6.9.1.1. Talar

Talar or Soffe is a semi-open space, common in most of Iranian houses of the central desert (Figure 54). In fact, Talar is an Iwan, which is open only in one side. In some regions, Talar and its peripheral rooms and spaces form the main structure of the building. This element has even been used in other structures, i.e. mosques, caravanserais and Ab-anbars. The common physical form of Talar is a stretched rectangle. In most houses, windcatcher is located behind Talar, however, in some houses, i.e. Lariha house in Yazd, windcatcher is completely separate from Talar and is connected to a dedicated room. Talar has a significant role in the overall configuration of spaces.

6.9.1.2. Windcatchers

Windcatchers are also important elements in the central desert cities. As mentioned before, the main role of windcatchers is supplying the summer residence with fresh cool air (Figure 55). Regarding the functions, windcatchers can be divided into two groups. In most of the regular houses, Badgir has a mere physical and practical function, while in houses belonging to well-known citizens; Badgir is a symbol of their power and wealth. In these houses the size of the windcatcher was enormous.

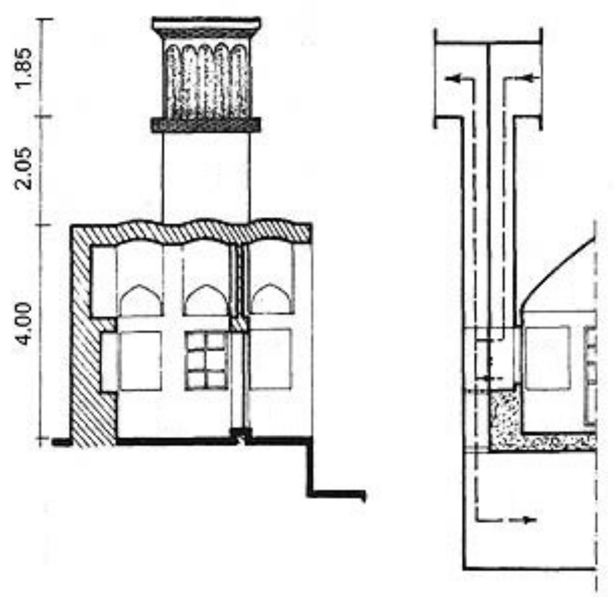

Figure 55: Section of a windcatcher in Yazd (Source: M. Abolfazli)

As stated previously, windcatchers are often located behind Talar, in which case they intensify the symmetry in the façade, otherwise they are present at one side of the Talar, into another room, which debilitate the symmetry.

6.9.1.3. Entrance

The entrances to the houses in the hot and dry region of Iran are almost identical to each other. The height of the supraporte is often equal to the adjacent wall and is often ornamented with patterns of bricks. Hashti was the filter space that came directly after the entrance and was the only space that is rather far from the courtyard. In most cases, Hashti was in the corners of the land plot and its size depended on the house and the owner of the property. The roofing system of Hashti was also diverse. On the sides of this octagonal space, there were other functions as well; stairway to the rooftop, access to the well and pews for meeting stranger guests.

6.9.1.4. Courtyard

Courtyards are the focal point of the introvert Iranian desert houses. In these houses, the courtyard is completely separated from the local environment, and a pleasant environment is created with vegetation and water pools. Moreover, courtyards played an important role in the configuration of spaces around them, through seasons.

Some houses had two courtyards (Figure 56); one in Andarouni, the private section, and the other in Birouni, the semi-public area. In some grand houses, a third smaller courtyard is also present, known as Narenjestan. As mentioned before, courtyards are often rectangular, however in some cases they are in form of an octagon.

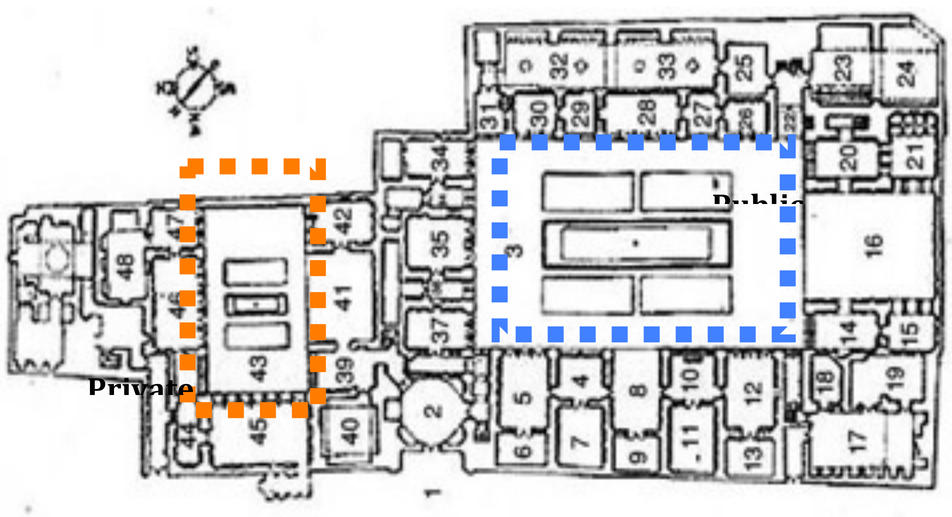

Figure 56: Public and private courtyards of Laariha House in Yazd (Source: ghoolabad.com)

Courtyards and their elements can be divided into two groups; a) level courtyards with water pools along their longs axis and two or four vegetation spaces parallel to the pool (i.e. public courtyard of Laariha House in Figure 56), b) courtyards with Godal-Baqche which were common in Naeen, Kashan and other cities in the hot and dry climate. Godal-Baqche and its surrounding spaces were in practice a part of the basement area. Moreover, through this lowered space in courtyard, access to Qanat water was provided. The soil dug out to build the Godal-Baqche was further used to make bricks for the construction of the main building.

6.9.1.5. Rooms

Based on their function and their appropriate season, rooms were called different names. The function of some of these rooms is described in the following:

- Sedari: work place, bedroom, used mostly in spring and autumn.
- Panjdari: Living room, place for entertaining guests, dining room, winter residence
- Tehrani: place for parties and guests dining room, winter residence

- Tanabi: bedroom, located between Talar and the room with windcatchers, summer residence
- Balakhaneh (Balcony): work place and bedroom, winter residence
- Gooshvareh: bedroom, library
- Korsikhaneh: a room with no opening into the courtyard, connected to winter spaces and dedicated to Korsi, a traditional heating system

Of the aforementioned rooms, autumn and winter spaces are located on north and western sides of the courtyard, while summer residence spaces were on the southern side, back to the sun. Kitchen was often located next to a winter room. These rooms were divided around the central courtyard, connected to each other via corridors and the yard.

The physical plan of these rooms was often rectangular and the dimensions followed the Iranian Golden Square. Rooms around courtyard were lighted through openings into the yard, which were protected against harsh climatic environment by Tabeshband and other shading devices. Other rooms without access to the yard were lighted through the roof.

Hozkhaneh

Hozkhaneh is a summer room with a water pool in the middle and it is common in many desert cities, especially in Yazd. In some instances, Hozkhaneh is in the semipublic area, next to the well house, while in other cases it is next to Talar.

Basement

Basement is the most important section of the house during hot and long summer days. In houses that are not equipped with a Godal-Baqche, the basement occupies all or most of the space under the ground floor and it is accessible via stairways in the courtyard. Different sections of the basement were connected either by stairways and courtyard or directly through corridors. The ground floor was raised to permit lighting of the basement through openings. In some case, i.e. Rasoulian house in Yazd, the basement not only occupies all the space below the ground floor, but also it extends further into the courtyard.

Payab

Payab is the coolest and deepest space in the house. Qanat water was channeled through this space and it was cool enough to store food in summer. The physical plan of this space was often octagonal, covered with a dome.

Roof

The roof was used during summer nights as sleeping area. In order to block visual access a round of wall enclosed the roof. There is also a small room on the roof, used for storing beddings.

Other spaces

Apart from the spaces stated above, every house possessed other rooms and spaces, such as bath, toilets, well house and various storage rooms, which were nonsignificant in comparison to the aforementioned areas.

6.10. Conclusion

Detailed analysis of Iranian traditional architecture and urbanism reveals several unique techniques, developed to improve human thermal comfort. Nonetheless, it should be noted that most of these climate-regulating strategies are intended for indoor environment. In other words, the outside climate is so severe that passive climate regulation is not very effective; therefore microclimates are created in enclosed spaces.

- Shading by high walls, arches and domes, trees, etc.
- Thick outer tissue of the structure as thermal capacitor
- Improved building orientation against unfavorable winds
- Creation of draught via ventilation channels
- High walls and narrow alleys, high H/W ratio
- Providing alternative spaces for extreme weather conditions
- Introduction of water to the environment for cooling and moisturizing air
- Lowering the building level below the ground level
- Internal migration
- Creation of oases in focal points of the built environment

The applicability, relevance and efficacy of these strategies in the contemporary Iranian context are explored in the next phase of the analysis.

Chapter 7: Analysis and Results II

7. Adaptation and Mitigation in the Ruhr

In order to establish a toolbox of different strategies against climate change, two projects were investigated. These projects recommend a series of practical strategies to address the negative impacts of climate change in the Ruhr region. The first project in this section is the Urban Climate Handbook[25] and the second one is the InnovationCity Ruhr. In this chapter these projects are introduced and explored. The suggested strategies that involve interventions on an urban scale are explained. Later on, the essence of these strategies and the ideas behind them are extracted and developed into a comprehensive and yet concise catalogue of possible solutions for the negative impacts of climate change. In the end, the applicability of these strategies in the Iranian arid cities is investigated.

7.1. The Urban Climate Handbook

7.1.1. Background

This project was funded by the Ministry of Environment and Conservation, Agriculture and Consumer Protection of North Rhine-Westphalia[26] and It was conducted in 2010 by Ruhr Regional Association (RVR) in partnership with Department of Applied Climatology and Landscape Ecology, University of

[25] Handbuch Stadtklima: Maßnahmen und Handlungskonzepte für Städte und Ballungsräume zur Anpassung an den Klimawandel

[26] Das Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz des Landes Nordrhein-Westfalen

Duisburg-Essen; Research Institute for Water and Waste Management at RWTH Aachen (FiW eV); and the German Institute of Urbanism.

In this project, the authors comprehensively analyze the Ruhr metropolitan area in terms of urban structure, demographic changes, air, and noise and water situation. They point out five urban climate phenomena that are caused or intensified by climate change, and will affect the wellbeing of citizens.

- The urban heat island (UHI)
- The modified wind field
- Change in the precipitation patterns
- Changes in air humidity levels
- Increased concentrations of atmospheric trace gases

The impact of climate change on the urban climate and thus on people and their urban environment exacerbate the stresses in the problem areas in the future.

Based on the specific threats of climate change against the urban environment in the Ruhr area, the following general tasks have been recommended in order to reach a climate-friendly city:

- Improvement of the quality of life, especially in urban areas with high density, in terms of thermal convenience; Preventing heat islands
- Optimization of ventilation throughout the city; generate and supply fresh, cold air
- Avoidance of air stagnation and barriers against air exchange
- Reduction of GHGs and air pollutants
- Identification and evaluation of climate-related strains on the entire city
- Comprehensive planning for crisis
- Consideration of the risks of flooding caused by extreme precipitation

These general objectives are reachable through a series of practical detailed strategies, each focusing on a single phenomenon.

In this research, the authors identify the problem areas within the Ruhr region, and then investigate how climate change will intensify these problems. Moreover, they offer detailed “action catalogues” in three subjects. These catalogues are in fact documentations of sensitivities and vulnerabilities of different sectors of the city against the changing climate. A number of strategies have been suggested in order to address each of these impacts.

7.1.2. Table of Strategies

Table 7: Summary Table of appropriate adaptation solutions in the problem field "heat stress", urban climate aspects

I	Framework of the system			Solutions
	Separate planning authorities (Department of Environment (Umweltamt) and Department of Planning (Planungsamt)		H1	Integrated collaboration between different planning authorities
	Structural and technical requirements		H2	Review of technical feasibility
	Lack of optimization measures		H3	Inclusion of modeling in the planning process
II	**Strains**	**Sensitivities**		**Solutions**
	Heat waves	Permeability, vegetation	H4	Limitation of buildings boundaries
			H5	Creation and preservation of open spaces; Unsealing spaces
			H6	Creating, remodeling and preservation of urban parks
			H7	Greening of the streets
			H8	Greening of the roofs
		Population density	H4	Limitation of buildings boundaries
		People over 65	H9	Information management, warning systems
III	**System failures**			**Solutions**
	Heat coming from buildings and structures		H6	Creating, remodeling and preservation of urban parks
			H7	Greening of the streets
			H8	Greening of the roofs
			H10	Greening of urban facades
			H11	Creation and preservation of fresh-air areas
			H12	Provision of open water areas, artificial lakes and fountains
			H13	Optimization of buildings orientation
			H14	Thermal insulation, tissue shading
			H15	Adopting suitable building materials
	Lack of night time cooling		H4	Limitation of buildings boundaries
			H11	Creation and preservation of fresh-air areas
			H16	Creation and improvement of air channels
	Poor ventilation		H4	Limitation of buildings boundaries

		H11	Creation and preservation of fresh-air areas
		H16	Creation and improvement of air channels
		H17	Prevention of slab buildings on hillside slopes
IV	Damage potential		Reductions
	Reduced quality of life/productivity	H18	Installation of shading devices
		H12	Provision of open water areas, artificial lakes and fountains
		H6	Creating, remodeling and preservation of urban parks
	Negative impacts on health	H9	Information management, warning systems
		H11	Creation and preservation of fresh-air areas
		H16	Creation and improvement of air channels
	Heat death	H9	Information management, warning systems

Table 8: Summary Table of appropriate adaptation solutions in the problem field "heat stress", urban water management aspects

I	Framework of the system			Solutions
	Separate planning authorities (Water management, urban and regional planning)		H1	Integrated collaboration between different planning authorities
	Structural and technical requirements		H2	Review of technical feasibility
II	Strains	Sensitivities		Solutions
	Increased evaporation	Urban vegetation with high water demand	H19	Increased irrigation of urban vegetation
			H20	Adopting suitable species of plants
	Dehydration of pervious surfaces	Vegetated and unvegetated surfaces with limited inherent defenses against dehydration	H19	Increased irrigation of urban vegetation
			H21	Increased use of vegetation on urban surfaces
			H22	Shading of service areas
	Warming of surfaces (semi or fully impervious surfaces)	High proportion of impervious surfaces with high thermal conductivity/capacity	H23	Adopting materials with lower thermal conductivity and storage capacity for road surfaces
			H22	Shading of service areas
		Near surface sand layers with high thermal conductivity and capacity	H24	Filling the trenches with suitable materials with reduced thermal conductivity and storage capacity
		Drink water facilities installed at minimum depth	H25	Increasing the depth of the distribution network
			H22	Shading of service areas
III	System failures			Solutions
	Increased water demand for irrigation in the public and private areas		H26	Use of excess local ground water
			E4	Creation of rainwater temporary storage and emergency waterways
			H27	Promotion of water saving activities during dry and hot periods
	Low ground water recharge due to greatly reduced permeability of dry soil		E1, E4	Renaturation of the impervious surfaces, Creation of rainwater temporary storage and emergency waterways
			H28	Planting of the urban areas with suitable varieties in order to improve the

			permeability of upper soil level through rooting
	Flood risk due to increased size of impervious areas (hard dried soil surfaces unable to absorb rainwater)	E	Refer to the section on extreme precipitation
	Warming of drinking water in pipes (affecting drinking water quality)	H29	Additional measures in water treatment
		H30	Insulation of the distribution network
		H31	Improved maintenance (Adequate flow, frequent rinsing and disinfecting)
IV	Damage potential		Reductions
	Damage to public infrastructure and private properties by rainwater runoff	E5, E8, E10	Informative measures, Measures of physical protection, Organized protective measures against extreme events

Table 9: Summary Table of appropriate adaptation solutions in the problem field "Extreme Precipitation"

I	Framework of the system			Solutions
	Separate planning authorities (Water management, urban and regional planning)		H1	Integrated collaboration between different planning authorities
	Structural and technical requirements		H2	Review of technical feasibility
II	Strains	Sensitivities		Solutions
	Fast and large amounts of runoff	Surface permeability level and land use	E1	Renaturation of the impervious surfaces
			E2	Space utilization for runoff and soil erosion reduction measures
			E3	Improvement of drainage system
			H8	Greening of the roofs
		Soil conditions in catchment areas	E1	Renaturation of the impervious surfaces
			E3	Improvement of drainage system
		Topography of the catchment areas	E2	Space utilization for runoff and soil erosion reduction measures
			E4	Creation of rainwater temporary storage and emergency waterways
			E5	Informative measures
		Presence of small urban open water	E5	Informative measures
			E6	Prevention of bottlenecks and runoff obstacles

		spaces (ponds)		
		Weak drainage system	E6	Prevention of bottlenecks and runoff obstacles
		Flow of water from higher streams into deep valley bodies of water	E4	Creation of rainwater temporary storage and emergency waterways
			E5	Informative measures
			E6	Prevention of bottlenecks and runoff obstacles
		Weakness of special structures, i.e. Pumping stations	E7	Ensuring the proper operation of important facilities
		Temporary construction sites	E4	Creation of rainwater temporary storage and emergency waterways
			E5	Informative measures
			E8	Measures of physical protection,
III	System failures			Solutions
	Overloading of drainage system		E2	Space utilization for runoff and soil erosion reduction measures
			E4	Creation of rainwater temporary storage and emergency waterways
			E3	Improvement of drainage system
			E6	Prevention of bottlenecks and runoff obstacles
	Flooding of roads, underpasses and cellars		E4	Creation of rainwater temporary storage and emergency waterways
			E5	Informative measures
			E8	Measures of physical protection,
			E9	Underpasses with bilateral drainage
	Soil erosion		E2	Space utilization for runoff and soil erosion reduction measures
	Uncontrolled discharge of mixed water into urban rivers		E5	Informative measures
IV	Damage potentials			Reductions
	Damage to the infrastructure and private properties		E5	Informative measures
			E8	Measures of physical protection,
			E10	Organized protective measures against extreme events
	Health risks		E5	Informative measures
			E10	Organized protective measures against extreme events

Table 10: Summary Table of appropriate adaptation solutions in the problem field "Dry periods"

<table>
<tr><td>I</td><td colspan="2">Framework of the system</td><td></td><td>Solutions</td></tr>
<tr><td></td><td colspan="2">Separate planning authorities (Water management, urban and regional planning)</td><td>H1</td><td>Integrated collaboration between different planning authorities</td></tr>
<tr><td>II</td><td>Strains</td><td>Sensitivities</td><td></td><td>Solutions</td></tr>
<tr><td></td><td>Little or no precipitation</td><td>Low awareness of future precipitation changes</td><td>D1</td><td>Research and knowledge transfer</td></tr>
<tr><td>III</td><td colspan="2">System failures</td><td></td><td>Solutions</td></tr>
<tr><td></td><td colspan="2">Increased water demand for irrigation in the public and private areas</td><td>E4, H26, H27</td><td>Creation of rainwater temporary storage and emergency waterways, Use of excess local ground water, Promotion of water saving activities during dry and hot periods</td></tr>
<tr><td></td><td colspan="2" rowspan="2">No ground water recharge</td><td>E3, E4</td><td>Improvement of drainage system, Creation of rainwater temporary storage and emergency waterways</td></tr>
<tr><td></td><td>D2</td><td>Artificial recharge through infiltration of excess surface water from the polder areas</td></tr>
<tr><td></td><td colspan="2" rowspan="3">Reduced mixed-water flow in the sewer system (no natural flushing by inflow of rainwater, a higher proportion of solid ingredients, effectiveness of sewage system compromised)</td><td>D3</td><td>Frequent maintenance of the network by operators</td></tr>
<tr><td></td><td>D4</td><td>Identification of network areas with particular reduced mixed-water outflow</td></tr>
<tr><td></td><td>D5</td><td>Adoption of hydraulically efficient pipe profiles or exchange for distributed pressure drainage in each network segment</td></tr>
<tr><td>IV</td><td colspan="2">Damage potential</td><td></td><td>Reductions</td></tr>
<tr><td></td><td colspan="2">Lower raw water availability for drinking and industrial purposes</td><td>E4</td><td>Creation of rainwater temporary storage and emergency waterways,</td></tr>
<tr><td></td><td colspan="2">Increased odor and vermin by deposits in the sewer network</td><td>D6</td><td>Removal of deposits</td></tr>
<tr><td></td><td colspan="2">Reduction of the hydraulic capacity by sewage deposits</td><td>D6</td><td>Removal of deposits</td></tr>
</table>

7.1.2. Description of Strategies

Strategies against heat waves

Table 7 and Table 8 give a general overview available via the assignment of appropriate adaptation solutions, for relevant urban areas to climate-related hazard potentials, for the issue of "heat stress", separately for urban climate issues (Table 7) and municipal water management issues (Table 8). In this section, individual adaptation and mitigation measures are explained with a short description or graphics.

In order to cope with future heat stresses, the urban design guidelines should be devised based on two main objectives; Firstly, to decrease the direct heat absorption, and secondly to create suitable aeration to secure cooling.

Some adaptation strategies, such as the green roofs, have technical requirements that need to be clarified in advance (H2). An efficient use of adaptation solutions is only possible if areas with high cost-benefit ratios are identified through assessment frameworks. In order to predict the intended effects of a proposed change in the urban structure, the use of a numerical simulation model is a suggested (H3).

Short-term actions to be implemented to reduce the heat island effect in the urban areas are greening measures in the street network and also greening of roofs and facades. Also, provision of small urban lakes and reservoirs is suggested as a short-term strategy.

Alterations in building design, such as building orientation, building wall shading; thermal insulation and the use of suitable materials can be summarized as medium-term measures to climate change adaptation. Planning of the open spaces can be categorized as long-term adaptation measures. The planners argue that because of the very slow rate of sustainable urban renewal in this context, there is much more pressure to act upon urban planning (Regionalverband Ruhr 2010):

> *"Adaptation measures for changes that arise only in the future must begin today".*

H1 Integrated collaboration between different planning authorities:

With the implementation of adaptation actions, cooperation in various sectors within the community is critical and influences the outcome of all the adaptation activities. The interests of all relevant municipal departments must be considered. Through an integrated collaboration between the various planning areas at the earliest possible time, it is possible to bring together the various concerns and to reconcile.

H2 Review of technical feasibility

For almost all the adaptation strategies, a review of the relevant technical feasibility is required. For example, in case of urban greening in the street network, the course of power transmission lines should be considered, or as of roof greening, the stability of building structures should be examined in advance.

H3 Inclusion of modeling in the planning process

Since the interactions between different climatic elements such as air temperature, humidity and wind, and a city are so complex, the effects of structural or other changes in a neighborhood cannot be predicted easily. Therefore, a numerical simulation model is a sensible solution in order to predict the effects of a proposed change in the urban structure. For example, an environmentally sound and economically efficient greening of urban areas is only possible through identification of areas with high needs and strategies with high cost-benefit ratio. Use of micro-scale climate models, such as ENVI-met is encouraged.

H4 Limitation of buildings boundaries

To ensure adequate ventilation throughout city, even with weak currents, smaller surface area and lower building density is needed. Between the reservation of urban areas and the goals of climate-friendly urban development, there are often trade-offs. A development of open spaces leads to compact settlement patterns, which are areas with higher sustainability in terms of transport and energy. On the other hand by the compaction of buildings, the heat island effect is amplified. Therefore it should be tried at least as a compromise, to seek development limits and development beyond that limit should only be allowed in exceptional cases. The careful design of the remaining urban open spaces can counteract the negative effects of compaction.

Around a city, there should be adequate open spaces left for the exchange of air into the inner city; especially when only a few open spaces are available as buffers between closely spaced cities. Therefore, to prevent the restriction of supply of fresh air, construction limits should be set in the outskirts. Inner-city green belts should be networked as much as possible.

Setting boundaries for a city has two more objectives:

- Protection of the outer space against any further development (Figure 58)
- Protection of urban regeneration areas against additional development (Figure 57)

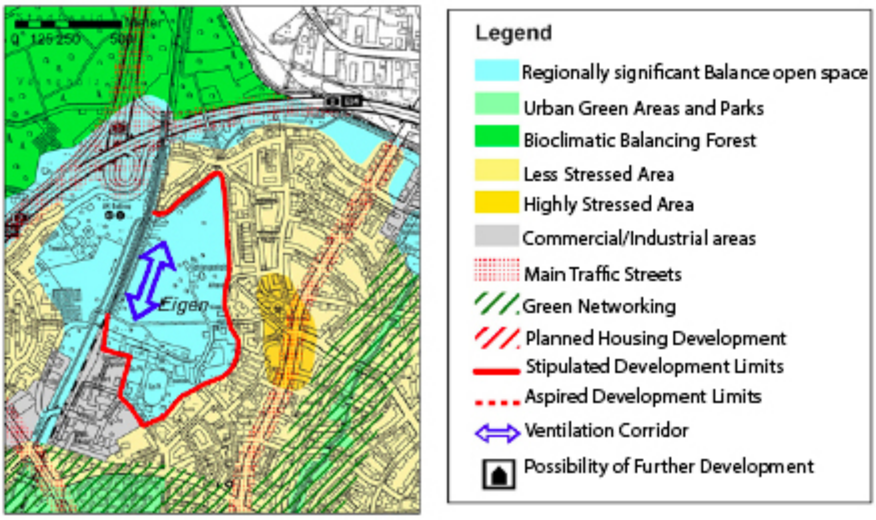

Figure 57: Protection of cold air production area from further development (RVR 2006)

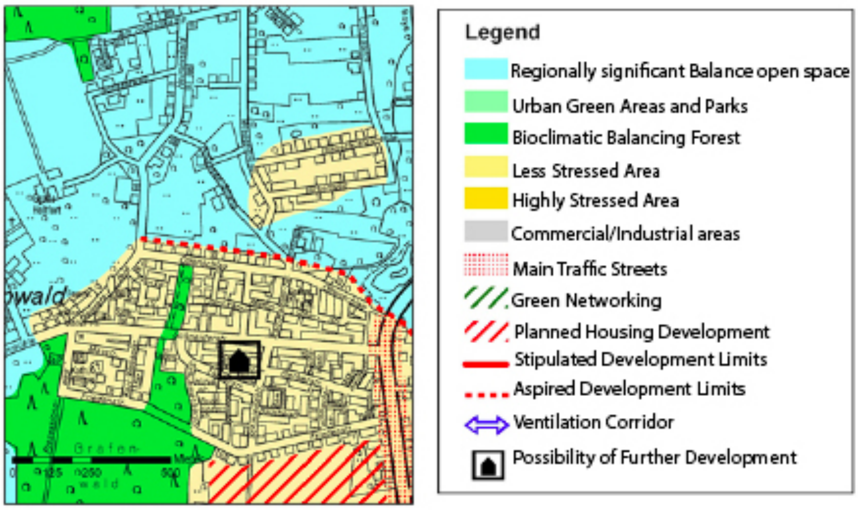

Figure 58: Prevention of convergence of two settlement areas (RVR 2006)

H5 Creation and preservation of open spaces; Unsealing spaces

With a sufficient surface area, a green open space can also have a climate-regulating function, besides its role in the urban context as a structural element. A special feature is the green belts as separation barriers between residential areas and emitting industrial and commercial areas or roads with high traffic. Moreover, green spaces act as air filters, diluting and filtering airborne contaminants, and decrease the heat island effect.

In the context of Ruhr area cities, the main obstacle is lack of space. Therefore, unconventional greening methods, such as greening of tram tracks are also suggested and a greater emphasis is laid upon greening of inner gardens within urban blocks.

H6 Creating, remodeling and preservation of urban parks

Urban parks play an important role as cooling agents. During the day, a conventional park, consisting of a lawn, shrubs and trees, can balance the temperature of the built environment around it, through evapotranspiration. At nights, this process is done by cold air exchange.

H7 Greening of the streets

Greening of the streets in the urban area with trees and shrubs can decrease the heat island effect. The shadow of the trees and evaporation and transpiration of the plants will moderate the temperature. At the same time, since streets are usually air channels as well, these plants will cool the air that circulates through the rest of the city.

Special attention should be given to the type of foliage selected for street greening. While a certain tree type with a large canopy can provide more shadow, it will also lead into accumulation of air pollutants on the street level. However, unless there is a significant source of pollution under the canopy, this effect can be ignored. Needless to say, types of plants should be chosen that are adaptable to the future climate.

H8 Greening of the roofs

Green roofs, as the smallest green spaces in the city, have also a positive impact on the temperature, air quality and energy consumption of a building and in large numbers they can even affect the microclimate of a neighborhood.

The foliage, the air cushion and the evaporation in the vegetation layer reduce the temperature of the roof in the summer and the heat loss of the building in the winter, therefore reducing the general energy demand.

Another positive effect of green roofs is the impact on the water cycle. 70% to 100% of the deposits are collected in the vegetation layer and through evaporation released back into the air. This reduces the moisture deficiency and helps to cool the air. Heavy precipitation will enter the sewer system with a delay, thus relieving the city sewer system (Wirtschaftministerium Baden-Württemberg 2008).

In case of the cities in the Ruhr area, municipalities are urged to create support programs and offer financial subsidies and incentives to promote green roofs both in the current built structures, and future developments.

H9 Information management, warning systems

A heat wave warning system and a tailored heat stress information management can reduce the health risks from heat waves. The German Weather Service (DWD) has already established an information system in order to alert the population in case of high temperatures, low wind currents and intense sunlight.

It is also necessary to provide vulnerable groups of the society, i.e. the elderly, with recommendations on how to protect themselves against heat waves.

H10 Greening of urban facades

The greening of urban façades acts in the same manner as roof greening, and decreases temperature, air quality and energy consumption. Although the impact of façade greening on the microclimate is relatively minor, they protect their host building again extreme heat events.

H11 Creation and preservation of fresh-air areas

The generation of cold and fresh air through a natural surface is determined by the thermal properties of the materials in that surface. Materials with higher density absorb more solar energy; therefore produce less cold air than those with less density. The size of these fields is important too.

Connectivity of fresh-air fields with the inner-city districts through fresh air corridors reduces the heat island effect.

Another trade-off happens here too; redevelopment of previously industrial areas can create a high-density residential district but at the same time eliminating the chance for a fresh-air surface.

H12 Provision of open water areas, artificial lakes and fountains

The evaporation of water consumes heat, thus cooling the air around it. Placement of water pools and fountains in the urban areas increases the air humidity and decreases temperature.

As water gains heat more slowly in comparison to air, it has a balancing effect on the temperature. Therefore it will be cooler than its surroundings in summer and warmer in winters.

H13 Optimization of buildings orientation

The spatial arrangement of buildings should be made with consideration to the sun and wind exposure. Through an efficient building orientation, not only can we reduce the summer time solar heat absorption, but also proper ventilation currents can be invited into the structure. However, this strategy only applies to the new development.

H14 Thermal insulation, tissue shading

In face of global warming, building cooling is becoming increasingly important. Conventional air conditioning requires massive amounts of energy in summer, thus have a significant negative effect on the climate. Thermal insulation and shading of the building walls will reduce the demand for cooling. South side pergolas are good examples of tissue shading. These strategies can be applied to both current and future developments.

H15 Adopting suitable building materials

Different materials have various rates and capacities at which they absorb heat. For example steel and glass absorb a large turnover of solar energy during the day and then give it back to the environment at night. Use of bright materials is encouraged in order to prevent heat absorption.

H16 Creation and improvement of air channels

An important component of urban air exchange is the urban air channels that connect the fresh air generation areas to the inner districts of the city. These channels can be divided into three categories

- Ventilation channels: moving massive amounts of air through the city, regardless of its temperature or hygiene status
- Cool air channels: transporting cool air, regardless of its quality
- Fresh air channels: pathways for clean air without temperature difference.

H17 Prevention of slab buildings on hillside slopes

Buildings with continuous slab structures can block the fresh air movement; therefore special attention should be paid to their location.

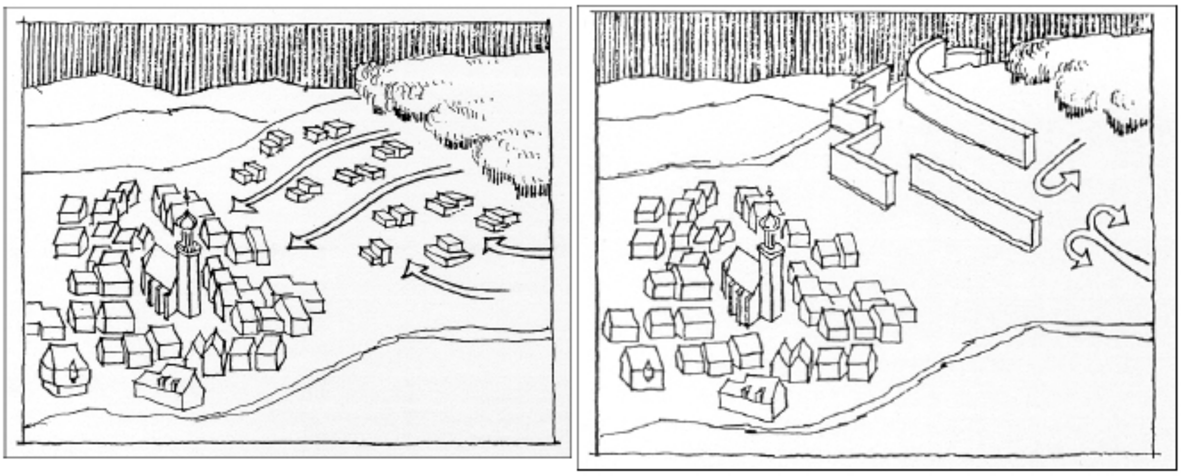

Figure 59: Permeable blocks (left) against slab buildings (right). (Wirtschaftministerium Baden-Württemberg 2008)

H18 Installation of shading devices

An easy way to reduce the heat loads due to direct sunlight during the day is the installation of shading elements. This will both improve the quality of life, and the productivity of the work force in inner districts.

H19 Increased irrigation of urban vegetation

Urban vegetation is very vulnerable in face of summer heat waves. Therefore artificial irrigation infrastructure should be prepared for times when the soil moisture and natural precipitation is scarce. In case of long periods of droughts and heat waves, this artificial irrigation will put extra pressure on the water sources, thus it is suggested to replace the native species with drought-resistant types (H20).

H20 Adopting suitable species of plants

Selection of plants with high drought tolerance, and low water demand is necessary, both for the greening of parks and urban street network.

H21 Increased use of vegetation on urban surfaces

Use of impervious materials in pavements leads to decreased rainfall absorption, which in turn causes the dehydration of soil in summer heat. This phenomenon has negative impacts both on soil erosion and ground water recharge and increases the risk of floods. The planting of such flat areas with shrubs reduces the drying out of the soil and increases the permeability of ground. Wherever planting is not possible, ground surface should be covered with artificial substances, such as mulch.

H22 Shading of service areas

Long lasting heat periods have negative effects on water distribution systems, for example increase rate of bacterial infections. Shading the areas where these pipelines pass will help decrease these negative effects. In case planting does this shading, urban climate and air quality are also improved. However, in areas where plants roots interfere with pipeline systems, artificial shading must be provided.

H23 Adopting materials with lower thermal conductivity and storage capacity for road surfaces

Since streets and roads in congested Inner cities can account for around 10% of the total area, they can contribute significantly to the warming effect. Asphalted or paved traffic spaces absorb solar energy significantly stronger than natural surfaces. Bright paving materials (materials with high Albedo) reflect much of the solar energy back into space and can reduce the heating effect on the piping system underneath.

H24, 25, 29-31 Measures taken by utility operators

During prolonged periods of heat, the temperature of water in the distribution system may increase. Even an increase of 1 °C - 3 °C leads to significant increase of bacteria. This increase in temperature is more substantial in areas with lower flow. To prevent an infection outbreak, sometimes - especially in densely populated areas with drinking water from surface water - service and structural adjustment measures are necessary.

The minimum depth of the piping system is advised to be not less than 0.80 meters. This layer of soil between ground level and pipes acts as an insulation. Regular maintenance of the distribution network by the operators is also necessary to insure acceptable water quality.

H26 Use of excess local ground water

The precipitation is projected to increase in winter months in many parts of northwest Germany; therefore there will be an increase in the ground water recharge, and rising water levels.

This excess water can be used for these purposes:

- Urban design features (fountains)
- Irrigation of urban plants
- Support water spaces (lakes and ponds) in parks

Furthermore, this water may be used for other general purposes such as street cleaning and car washes.

H27 Promotion of water saving activities during dry and hot periods

There should be enough preparation for water shortages. Water conservation is not only limited to residential areas, other sectors, e.g. industries, need to consume less water in drought periods as well. However, this decrease in water consumption will lead to less flow in waste water system, which brings about other problems.

H28 Planting of the urban areas with suitable varieties in order to improve the permeability of upper soil level through rooting

Heat-induced dehydration of upper soil level will decrease the penetration of the rainfall into the soil. The consequences can be increased soil erosion, reduced groundwater recharge rate and in particular significantly increased rainfall runoff in the urban drainage systems, also in deeper areas of settlement and infrastructure systems, depending on the efficiency of the drainage systems. Improved drainage is achieved by planting with vegetation whose roots loosen the ground. A uniform rooting in the upper layers of soil improves permeability of soils.

Selection of plants needs extensive attention. While these plants need to tolerate droughts, their root system should be powerful enough to penetrate dehydrated soil.

Strategies against extreme precipitation

In field of urban water management, measures to reduce runoff through improved infiltration are necessary in the short term. Measures against system failures and reducing vulnerabilities require more technical and financial resources, therefore only possible for medium to long-term implementation.

E1 Renaturation of the impervious surfaces

Impervious surfaces are either created by their material (Tar, concrete) or extreme compression (by compactors). These impervious surfaces disturb the water cycle. They decrease the infiltration of rainwater; therefore reduce the ground water sources recharge. It is highly recommended to increase the permeability of these surfaces by exchanging them with suitable coatings such as gravel and grass.

E2 Space utilization for runoff and soil erosion reduction measures

When planning for a new development or reconstruction of a current district, especially in vicinity of hill slopes, investigations should be performed to find out the possibility of flash floods and landslides and suitable preventive measure must be adopted.

E3 Improvement of drainage system

In areas with high degree of imperviousness, rainwater cannot penetrate soil. Increased penetration is achieved by renaturation of surfaces (E1) and plants whose roots loosen the soil. Several infiltration technics are suggested, each with its own pros and cons.

E4 Creation of rainwater temporary storage and emergency waterways

If during heavy rainfall drainage systems fail and overflow, then there should be emergency waterways above ground, directing water specifically into natural retention facilities and areas, in order to prevent damage to infrastructure and the built environment.

E5 Informative measures

The urban population must be aware of the threats against them, and they should be supplied with recommendations of what to do in face of a disaster.

E6 Prevention of bottlenecks and runoff obstacles

Bottlenecks and obstacles in the drainage system will cause the facilities to overload during heavy rains. Regular maintenance is required to ensure these will not happen.

E7 Ensuring the proper operation of important facilities

Special structures such as pumping or hoisting stations need to perform their tasks even in critical situations. Therefore, measures should be taken to secure the energy supply and the functioning of this technical equipment. Independent power supply, flood alert system and flood protection layers are examples of these measures.

E8 Measures of physical protection

If a settlement is located in a flood prone area, short and long term measures should be adopted in order to ensure the physical safety of these structures. These measures should both secure the building against surface waters (elevated entrances, sealed doors and windows in the basement) and the rising water in the sewage system.

E9 Underpasses with bilateral drainage

After a heavy rain, and especially with a weak drainage system, water collects in lower areas of the urban area, mainly in underpasses and tunnels. Retention or drainage ditches, applied one or both sides of the road and independent from the sewage system can be helpful at these times.

E10 Organized protective measures against extreme events

The protective measures in face of extreme events come in three groups

- Mitigation: preventive actions which reduce the risk of a disaster
- Adaptation: actions which make disasters more manageable
- Recovery: rescue and reconstruction activities that take place after the outbreak of an extreme event

A regulated cooperation and a functioning communication between the participating rescue units and leaders are essential.

Strategies against dry periods

D1 Research and knowledge transfer

Especially in relation to the future possibly prolonged periods of drought, authorities, population and the utility companies are often not adequately prepared for the expected changes of the rainfall in summer and winter months. The technical regulations are often not adapted to the projected climate conditions. It is therefore necessary to continue research on the impacts of climate change and the possibilities for adapting to these impacts. The results and findings of the research should be available to public.

D2-D6 Measures taken by the municipal water authorities/ utility operators

The measures D2 to D6 provide strategies for municipal water authorities and utility operators, in response to the expected increase in longer dry periods. In case of a prolonged drought, the operators of sewer systems should examine their operating strategies including maintenance, inspection and cleaning of sewer networks and adjust them if needed. For example, during long dry periods natural flushing of sewer networks by rainwater are no longer guaranteed. As a result, deposits of solid ingredients in the sewer system can impair the sewage system. Technical measures, such as frequent flushing of the entire network can prevent this.

If sedimentation has already occurred in the network, leading to odor or vermin nuisance or reduce the hydraulic efficiency, it can be removed by high pressure flushing and possibly by the use of chemicals or machineries. In case of significant infestations, pest control by professionals or renovation of individual channel sections is required.

7.2. InnovationCity Ruhr

7.2.1. History and Background

The Ruhr Initiative Group (Der Initiativkreis Ruhr) is a consortium of 68 leading business companies. This group initiates, funds, moderates and supports projects in order to develop and improve the Ruhr area, in economy, science and culture.

In early 2010, the Innovation City Ruhr competition was introduced. The objective was to choose a typical part of the Ruhr area, with a population of around 70,000 as the pilot area for many investment projects. The goal is to create a model city for the renovation of the entire Ruhr area. Municipalities were asked to hand in their proposals for developing energy efficiency and reducing CO_2 emissions. The ICR considered the industrial, residential, commercial, trade, services and transport sectors alike: Existing housing estates and industrial areas were to be converted into attractive energy saving neighborhoods and community facilities such as swimming pools or kindergartens suitable with the future environment. Moreover, "Green" industries and companies are encouraged to settle in this area. This project was designed to be a pioneer in so many aspects, even in electric mobility.

The Ruhr cities of Bochum, Bottrop, Essen, Gelsenkirchen / Herten and Mülheim were nominated in the first selection in June 2010 by an independent jury for the next round. Finally, in early November 2010, the jury among the five finalists selected the pilot area and named the city of Bottrop, the InnovationCity Ruhr. Therefore, by 2020, an area that mainly comprises the south of Bottrop will be converted into a city of the future climate.

The motto of ICR is "Blauer Himmel. Grüne Stadt". The blue sky symbolizes the environmental aspects of the project, for example, the measurable reduction of CO_2 emissions. The green city stands for a better quality of life, in places of living and working, and other general areas of the city (ARGE IC Ruhr 2013).

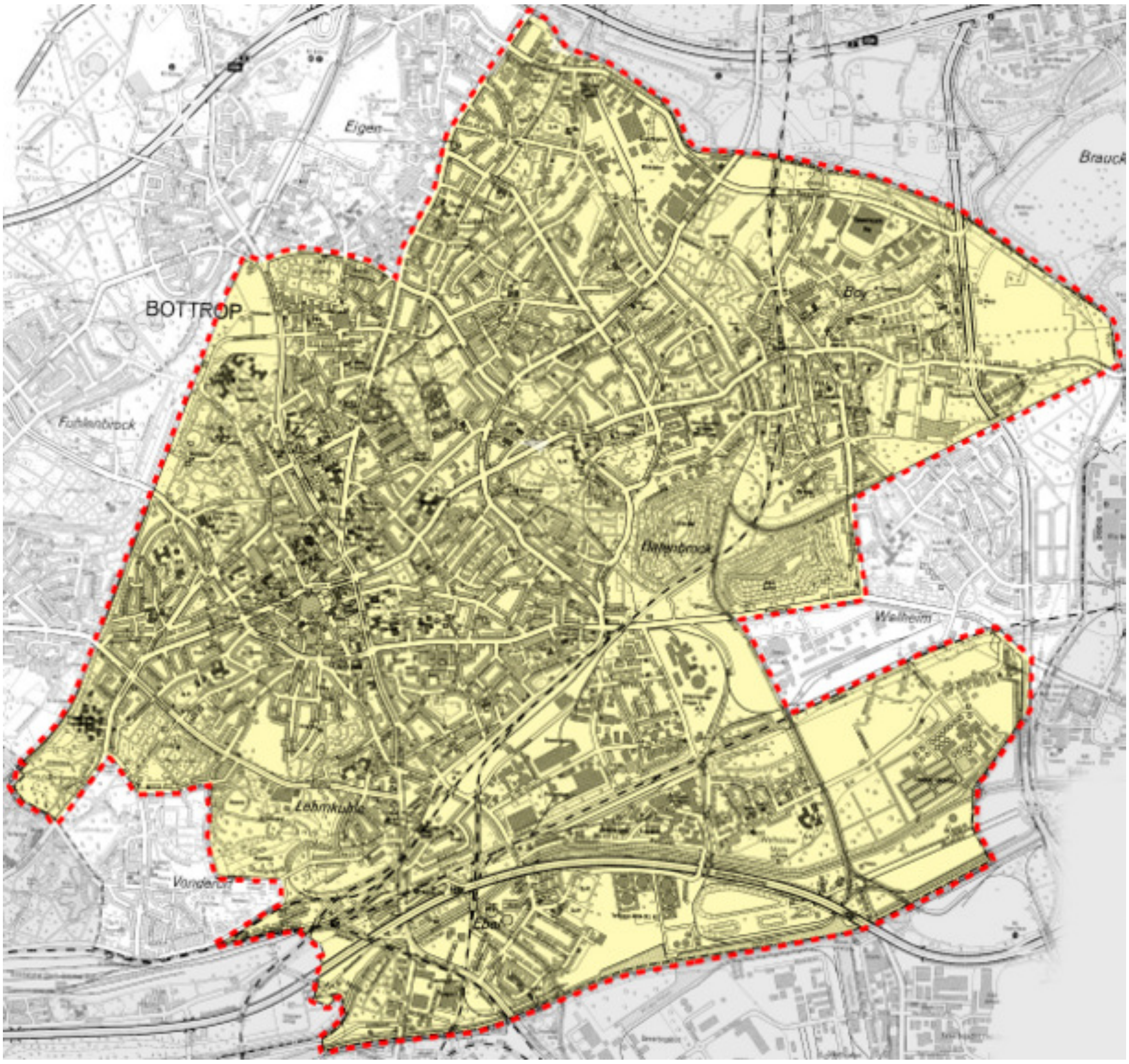

Figure 60: Pilot region boundaries (source: www.icruhr.de)

7.2.2. The Master plan

The master plan sets clear targets for climate-friendly transformation of an entire pilot area with 70,000 inhabitants in the heart of Bottrop (Figure 60). The objective is to decrease emissions of climate-damaging CO_2 50% by 2020 and at the same time make the city greener and more livable. The master plan InnovationCity Ruhr points the way to goal; not just on paper, but with many concrete projects to be implemented over the next few years. It is also a "road map" for the implementation and shows where the activities and projects can save CO_2 emissions in the areas of housing, employment, energy and transport. It also specifies intermediate targets for the period up to 2020 and makes their achievement verifiable.

The master plan is a key project of Bottrop Innovation City Management GmbH, which has contracted a consortium of four engineering, planning and consulting firms with creating the plan: These are the AS & P - Albert Speer &

Partner GmbH (Frankfurt), the Office Drecker (Bottrop), Conlab Management Consulting GmbH (Dusseldorf) and the Gertec GmbH (Essen).

The first draft of this Master Plan was publicly published in October 2013, and after revision it is planned to be finalized by March 2014. Starting from April 2014, many projects and activities will be implemented in the pilot region according to the Master Plan.

This Master Plan comes in two separate parts. The first volume is the analysis of the context in which the strategies are going to be implemented. These analyses were performed in six distinct areas of activity[27]:

- Residence
- Working
- Energy
- Mobility
- City
- Activation

The potentials of the pilot region are analyzed and investigated. The pilot region is divided into seven smaller focus areas. Subsequently, strategies are recommended in every activity field.

In the second volume, a project atlas is introduced. These projects cover all the areas of activity and each of them is designed to follow a number of strategies described before.

In this research, the focus is on those strategies that are directly involving the urban environment. Therefore, the strategies suggested for the fifth area of activity, City, are investigated in detail.

[27] Handlungsfeld

7.2.3. Table of Strategies

Table 11: Development goals and strategies

DEVELOPMENT GOALS AND STRATEGIES: CITY		
Development goal	Strategy number	Strategy description
ST A Use of existing land resources through conversion for the expansion of the green residential areas in Bottrop	ST A.1	Improve less-used areas in the settlement structure
	ST A.2	Mobilize existing infills
	ST A.3	Conversion of former industrial areas for new uses
	ST A.4	Densification of block interiors
	ST A.5	Assignment of new attractive uses to former outdoor sport facilities
ST B Protect, renew and develop the economy in a climate-friendly fashion	ST B.1	Promote Flächenkreislaufwirtschaft[28], Protect existing business areas
	ST B.2	Promotion of technical and creative renewal of existing businesses, together with brand making
	ST B.3	Develop modern business areas and foster targeted resettlement policy
ST C Redevelopment and extension of existing public buildings	ST C.1	Use decentralized urban service offices
	ST C.2	Reuse of the former school buildings and their surrounding areas
	ST C.3	Innovative reuse of former church buildings
	ST C.4	Demand-oriented reuse of sports, cultural and recreational facilities
ST D Promotion of mixed-use and multi-functional areas	ST D.1	Mix compatible uses in the districts
	ST D.2	Safeguarding existing uses and further development as needed
	ST D.3	Make quarters fit for the demographic change
	ST D.4	Promotion of social and cultural reference points in the quarters through redevelopment
ST E Protection and development of identity-creating structures	ST E.1	Promote identity-creating and formative structures
	ST E.2	Cautious further development of cultural heritage areas
	ST E.3	Climate-conscious upgrade of roads and urban areas
	ST E.4	Securing visual connections and orientation points throughout the city
ST F Safeguarding and strengthening of centers and supply structures	ST F.1	Improve the attractiveness of the inner city core
	ST F.2	Strengthen decentralized supply structures to secure primary services close to residents

[28] The Circular Flow Land Use Management is a holistic strategic approach to (re)using brownfield sites and reduction of land consumption, covering requirements of climate protection, energy efficiency and environmental remediation.

ST G Preservation and development of open spaces	ST G.1	Proper maintenance and climate-friendly development of green areas and open spaces
	ST G.2	Create and maintain new green structures, considering the changing climate (i.e. dismantling buildings, unsealing[29] open spaces, greening buildings)
ST H Activating the potential of open spaces: promoting attractiveness and multi-functionality of unsealed open spaces and green spaces	ST H.1	Improve public and semi-public open and green spaces (i.e., functionality, quality and accessibility)
	ST H.2	Improve private green areas (including open spaces near buildings)
	ST H.3	Maintain and develop urban-related land-uses
	ST H.4	Produce renewable energy in and from green areas
ST I Networking through preservation and development of open space structures	ST I.1	Preserve and develop road side green structures
	ST I.2	Preserve and develop rail side green structures
	ST I.3	Preserve and develop green structures along the waste water network
	ST I.4	Preserve the green network of the Emscher landscape park and further develop them
ST J Restoration and enhancement of natural water balance	ST J.1	Develop artificially made and anthropogenically altered flows and ponds as strong structural elements in the ecosystem
	ST J.2	Resurrect old water structures and create new natural water basins
	ST J.3	Enrichment of natural groundwater balance while maintaining the groundwater quality and the efficiency of drainage system
ST K Development and expansion of a resource-conserving rainwater and wastewater management	ST K.1	Separation of dirty and clean water discharge
	ST K.2	Development and promotion of measures for decentralized rainwater treatment
	ST K.3	Energetic optimization of drainage infrastructure
ST L Development and implementation of a water sensitive urban development	ST L.1	Convey the consequences of climate change on urban structures and integrate climate adaptation measures into overall planning concepts
	ST L.2	Learning with water - environmental education for children and adults
	ST L.3	Designing with Water - Upgrading of urban structures
ST M	ST M.1	Activation and planning of InnovationCity Ruhr

[29] Making the ground permeable

Further embed climate-conscious urban redevelopment in municipal planning and management		I Model City Bottrop with regional actors and planners
	ST M.2	Use planning tools intelligently and with consideration of goals for climate protection in Bottrop

7.2.4. Description of Strategies

7.2.4.1. ST A: Use of existing land resources through conversion for the expansion of the green residential areas in Bottrop:

According to analyses, there is already enough space needed for the residential developments of 2020 within the current limits of the city. The quality of life is high, due to low building density and high urban greenery, but this has led into far-flung dispersed settlements. Lower density creates further problems for the citizens, as they have to travel farther distances everyday. In order to improve the CO_2 balance in the pilot region and throughout the city, the InnovationCity Bottrop should focus more on cautious development in the settlement structures and responsibly deal with their land reserves.

Development on a large scale, outside of the current limit of the city should be avoided in any case. Instead, existing land reserves through valorization or conversion should be used sustainably and also the potential for more compact residential blocks should be considered.

ST A.1 Improve less-used areas in the settlement structure

Within the urban limits, there is already a very high potential for development, including underutilized lands in an attractive location in green and open spaces, with very good service coverage or good access to public transport. This is the optimal way to secure and stabilize long-term results of land management. The local authority has the task to identify these opportunities and thus stimulate developments. Future use of each plot should be determined in consideration of urban development, energy and climate issues.

ST A.2 Mobilize existing infills

Undeveloped land plots within the settlement structure posses a high potential for further development. Not only they provide more residential space, (ergo increasing the population density), but also they act as noise barriers.

As energy- efficient new buildings they can continue to provide a catalyst for further energy-saving renovation measures in the neighborhood, and as energy-producing buildings, they can be a part of an inter-building energy exchange network. Within the pilot region they are largely individually owned, so therefore any action by the city is faced by many difficulties.

ST A.3 Conversion of former industrial areas for new uses

Especially when long-established businesses close in mixed neighborhoods, a window of opportunity opens for urban developments in these sites with land uses with higher value, such as residential. More inhabitants mean more livelihoods in the neighborhood, a better utilization of community facilities and public transport links and more customers for the local merchants and traders.

In addition, new housing will help improve the social structure and pollutes the neighborhood with less emission than commercial buildings.

ST A.4 Densification of block interiors

The greened block interiors have a potential for more densification and internal development. However, this development must be carried out with caution and in accordance with surrounding buildings. The low building densities in Bottrop city are a problem in the provision of attractive public transport services and for the maintenance of social infrastructure and local shopping deals. Therefore, the development of housing aims on one hand at increasing population density, and on the other hand, at the coupling of creating living spaces with green and open spaces.

ST A.5 Assignment of new attractive uses to former outdoor sport facilities

The city of Bottrop will no longer be able to maintain all of its sports fields in future. Therefore, re-use concepts for at least about 0.7 ha should be proposed.

These are usually associated with middle schools in the district or at the edges. Depending on requirements, there is a high re-use potential in the development of additional living space and/or the creation of new community or publicly used green and recreational areas.

7.2.4.2. ST B: Protect, renew and develop the economy in a climate-friendly fashion

An adequate supply of attractive and competitive commercial space is important for the success of the climate-friendly urban redevelopment in Bottrop. This is the only way that companies can be held on-site or resettle into this city. More commercial taxpayers strengthen the financial capacity of municipalities, reduce unemployment and help to reduce the amount of social transfer payments. Companies and private households will be able to invest on climate protection and energy conservation.

Similar to most cities in the Ruhr area, the majority of businesses in Bottrop still are related to mining industry. In the area of economic development, the main challenge is the introduction of future-needed uses and promotion of conversion without loosing the identity of the old industrial landscape.

Bottrop has a high number of outgoing commuters (around 6000 people) and with the closure of the last mine in 2018 this number will increase even more. The projected increase in the commuter balance is mainly because of the drop in the number of incoming commuters after the discontinuation of mining facilities. In order to confront the negative impact on the labor market, alternative workplace should be offered to around 1,100 people who are depending on this industry in Bottrop. Highly educated people tend to look for jobs in other cities, such as Dortmund and Düsseldorf, as they have more opportunities in the job market. However the quality of life in Bottrop urges many workers to take the daily commute to the workplace in other Ruhr cities. In this context, the purchasable home ownership and the green quarters certainly play an important role in bringing new citizens into Bottrop.

Nevertheless, establishment of companies in knowledge-intensive industries with higher skilled jobs (e.g. research and development) through prudent management and development of business areas is very important.

ST B.1 Promote Flächenkreislaufwirtschaft, Protect existing business areas

A circular flow land-use management in economic areas is essential not only for the medium-term major mining areas for Bottrop. In this case, perspectives and ideas should be developed on a short-term basis. Shortly available areas represent a valuable potential for the economic development of the city, which can be harnessed by means of active re-use management. Through the reuse of derelict land, further development is possible, which contributes to the overall site security.

Concrete approaches to reuse should be developed. Re-use scenarios, - especially in economic areas in central mixed situations - should consider the possibility of alternative, higher-quality developments.

Here it is important to weigh in each case whether such conversion to residential or mixed construction areas may be more advantageous than the continued use as agricultural land. In the case of a conversion, the creation of equivalent replacement land for commercial settlement should be sought elsewhere.

ST B.2 Promotion of technical and creative renewal of existing businesses, together with brand making

Commercial areas are quickly becoming obsolete. While new commercial areas are exemplary in shape and open space planning, the industrial areas in the south Bottrop have a cluttered image. A major reason for this is the concentration of services of scrap metal and old cars in these areas in recent years, but also the inadequate situation for stationary traffic and the neglect of public space. The increasing level of disorder persuades local businesses to invest in their own real estate business. To make such areas more attractive in the Bottrop south and also ideal for relocations, it is important to continuously update the inventory areas and develop conclusive area profiles.

Such renewal may be affected by actions at an individual company level or through holistic urban planning approaches, such as specific settlement policy or renewal of public space. On the level of individual firms, it's all about measures such as energy-efficient renovation of the premises, the optimization of operational procedures, use of renewable energy sources or waste heat or by measures such as the partially unsealing of transport and storage space. Therefore, it is important to specifically address the operations and personally seek to make tangible benefits and advantages carefully. If carrying out unusual or considerably disturbing operations, it may be appropriate to seek cooperation with the concerned company for alternative locations in the city, and thus to achieve an enhancement effect in the current industrial area and possibly to create space for expansion for interested surrounding businesses.

On the overall level, however, there are issues that can improve the image of a business park crucially, such as the quality of public spaces, the reorganization of the moving and stationary traffic or urban greening. But also a specific settlement policy by the city, which directs operations in the appropriate areas with certain orientation and sector, contributes to profiling of commercial locations. Also the integrated consideration of adjacent commercial and residential areas can - in terms of energy consumption and CO_2 emission situation - be interesting and give impetus to the industrial park renewal.

ST B.3 Develop modern business areas and foster targeted resettlement policy

The strategy described in ST B.2, profiling of existing commercial areas should be demanded also ideal for new areas. So should in particular the issues of energy and environmental technology in the area of future economic policy find their express into account, establishment of small and medium-sized, highly innovative companies in these industrial regions should be endorsed. However, it also applies to the provision of space for craft businesses and they should not be neglected.

An example where technology-oriented firms and the crafts could be combined together is the business and technology park Welheimer Mark, for which a preliminary feasibility study will be developed.

7.2.4.3. ST C: Redevelopment and extension of existing public buildings

When public buildings or groups of buildings lose their use for municipal purposes, opportunities for change in terms of climate-friendly urban redevelopment arise. These changes should improve the quality of life and urban design. Often, public institutions are also identifying locations in the neighborhood, therefore a careful re-use of socio-spatial functions such as meeting places for the young and old, should be considered. Also, the re-use of churches and the new-use / re-use of cultural, sports and recreational facilities (e.g. outdoor sports halls and fields) in future Bottrop, are issues that should be addressed with consideration of climate change mitigation and adaptation.

A central theme in the re-use of public property by third parties is often unrealistic revenue expectations of the city, which may hinder the development. The change in use finally offers the opportunity to explore, support and finance alternative models for community facilities in neighborhoods.

ST C.1 Use decentralized urban service offices

The city of Bottrop intended to concentrate all municipal offices at few sites located close to each other in the city center. Thus the medium to long-term introduction of numerous distributed service offices in the neighborhoods give an entirely new experience. The central task of the organization of these offices will be to fulfill the needs of the adjacent areas and provide the best possible service to the local residents. This new window of opportunity offers a new chance for further development, both in the neighborhoods and downtown at the same time.

ST C.2 Reuse of the former school buildings and their surrounding areas

The number of school students in Bottrop is falling and according to the school development plan of the city, some school buildings will no longer serve as an educational facility. This offers a chance to re-use the buildings and their surrounding area for new purposes. Depending on the conditions of the building many options are available. The facilities can be used for residential or social community uses, or even renaturation can be considered. Theses developments should grow based on the local use-related needs and city-climatic / open space conditions.

ST C.3 Innovative reuse of former church buildings

Societal changes in Bottrop have resulted in closure of some religious institutions. Apart from their sacred use, they are the architectural history of the city: they are often formative elements of the cityscape and also have a high identification value for the citizens in each district. Therefore, it is very important to revive this type of urban space and architectural quality through innovative use of ideas. Monument protection and copyright issues are common and urgent challenges. Also, especially with the large volume of such buildings, financial costs are an important factor.

ST C.4 Demand-oriented reuse of sports, cultural and recreational facilities

Cultural, sport and leisure facilities that are no longer utilized or become too expensive due to their high maintenance costs for the public sector, offer a potential for new uses. If building structure and floor plans are too inflexible or inappropriate for a new use and / or the energy-efficient renovation effort is not guaranteed to have acceptable results, renaturation can also be considered.

It should be considered that renaturation of surfaces can contribute to the climate and quality of life at the same time.

7.2.4.4. ST D: Promotion of mixed-use and multi-functional areas

As a result of its history Bottrop has ample green neighborhoods with low construction and population density. These neighborhoods are heavily influenced by mono-structural residential use. Low-density neighborhoods generate weak impetus to the emergence of attractive additional uses for services or spending leisure time. The creatively economic re-use of commercial real estate, which is quite successful elsewhere, is difficult in Bottrop, due to the lack of a certain "critical mass" of users. Nevertheless, it will be important that Bottrop considers the potentials available via the promotion of mixed-use and functional diversity in the city and suburbs, because they are the keys to a city of short distances, low traffic and an improved quality of life.

On the subject of mixed use is the citywide level, of course, the aspect of providing quantitatively and especially qualitatively reasonable commercial space is very important. The demographic change is a challenge for the Bottrop neighborhoods, although the shrinkage in the coming decades will be less pronounced than in other cities of the Ruhr. Issues such as the regeneration in the structurally heterogeneous but functionally monotonous single family housing districts of Bottrop neighborhoods are important.

Here, in a sense, is the "chicken and egg" problem: If community facilities and schools are not at a desirable level on the local scale, young families on house search from Essen or other cities will no longer move to the southern parts of the city of Bottrop, although their influx is required for those facilities to continue to operate.

The local and regional attractiveness of residential areas depends also on the social and cultural reference points at close range, mainly for children and young people, who are not able to drive a car. Flagship projects such as Berne Park as meeting places and places of leisure for children, youth and seniors can also lead the way for the districts as role models.

ST D.1 Mix compatible uses in the districts

The protection and promotion of mixed use in the district makes a positive contribution to sustainable urban development. The abundance of easily reached services not only promotes an environmentally friendly local mobility, but also the vitality and comfort of everyday living locations. Within the pilot region, the approach is especially for the mono-functional residential areas to combine uses compatible with each other and preserve existing mixed uses. This can for example be achieved through the promotion of residential and work places in the district. Existing mixed-use districts or community centers can be stabilized by a functional development (or enhancement).

ST D.2 Safeguarding existing uses and further development as needed

The structures with the right type of use in the right place are essential for a future-oriented urban development. This dynamic should be controlled intelligently and sustainably, for example, by the "joint use" of available oversized property of third parties. Through the sustainable utilization of property, devaluation processes are avoided through maintenance backlog and use of the existing infrastructure, thus strengthening the existing pattern of use.

ST D.3 Make quarters fit for the demographic change

The demographic change presents the challenge of preparing neighborhoods and infrastructure for older people, but also paying attention to the pursuit of the youth and families to address the threat of obsolescence. To implement this repertoire, mixed generational housing projects and neighborhoods should be offered, as well as offers for old citizen housing with support services that enable older people to remain in their ancestral district. The creation of such offers should be neighborhood friendly, and the improvement of the quality of stay should be sought in the public space as a value for the environment.

The large, typical for Bottrop, private and semi-public green spaces, and also the public space, provide a potential for accessibility and user-group-specific enhancement in the neighborhood. To make Bottrop fit for the change of generations, means to develop customized solutions for young and old, the offer for a space for a neighborly coexistence, and on the other hand, retreat spaces for special user groups.

ST D.4 Promotion of social and cultural reference points in the quarters through redevelopment

Places for culture and leisure are urban meeting places with high social commitment and integration effect. These places bring people together and engage them in social activities. Therefore, as far as financial resources allow, these places should be supported.

With the change in local demography, the opportunity and the need for intergenerational programming and realignment of social or cultural community facilities arise. In addition to innovative use of ideas here especially economical solutions and initiatives of the users are needed.

7.2.4.5. ST E: Protection and development of identity-creating structures

The city of Bottrop is a typical piece of the Ruhr area on the transition zone between the Emscher and Münsterland and has settlement structure and open space spatial qualities that must be preserved. The urban texture of the pilot region is dominated by one-and two -family house types and small multi-family houses of different age groups, which are often mixed colorfully. In this highly heterogeneous city, it is important to maintain and preserve identity-building public spaces, streets and structures. This is in particular the working and living culture of the Ruhr area in the mining-industrial era. Old colliery houses with stables for small animals and the deep plots for partial self-sufficiency of the residents are only one example.

Especially when it comes to the old building facades, conflicts with the energy renovation of existing buildings can certainly occur. The scenic frontlets of the mining industry in the form of slag heaps have meanwhile become landmarks of the city (tetrahedron) and attractive recreational places (Alpine Center). Other areas such as Prosper II are also available for grouting as a potential for new, attractive open space and urban development after the end of coal mining.

Also no longer needed roads and obsolete hydraulic structures (Emscher conversion) should be developed in a way, that the character and history of the city of Bottrop landscape remain visible and tangible, but a value for city and climate arises.

ST E.1 Promote identity-creating and formative structures

Due to the mining industry, the pilot region is dominated to a large extent by settlement and open spaces. Mining settlements, pile structures, industrial monuments and the Emscher and its technical buildings are vital for the identity of the townscape. Supplemented by city formative structures, cultural, religious or social reference points within the neighborhoods create a structure, whose complexity and diversity creates the typical local character. This character should be obtained and extrapolated in the context of climate-friendly urban redevelopment.

Inevitably, the necessary adjustments to the changing urban society and climate have impact on the image of the city. Transformations, energy-efficient renovation and modernization of buildings or the creation of climate-friendly urban spaces must therefore be approached with care and sensitivity and lead to sustainable and responsible alterations in the cityscape.

However, An all-musealization of old plant parts by widespread protection should be avoided. Particular attention should be paid to the opportunities that arise from brownfield sites and unneeded infrastructure (old Güterbahntrassen) for the open space development and networking in the regional and urban scale. These can be considered as new paths for the discovery of industrial, urban and cultural landscape Ruhr.

ST E.2 Cautious further development of cultural heritage areas

Bottrop has large-scale mining settlements, monuments and statutes. Retail and natural monuments that are mainly concentrated in the downtown, supplement these sensitive areas of action. The challenge of energetic improvement of buildings and urban spaces is to find solutions that aim with the highest priority on the preservation of the townscape character and only aspire to the highest possible level of energy efficiency with the second priority. A further development of cultural heritage area in the settlement structure should be performed carefully and in compatibility with the typical local character.

ST E.3 Climate-conscious upgrade of roads and urban areas

Significant urban and street spaces include areas and buildings that need to be protected and developed because of their existing identity-forming impact on the entire city, a city's image and the relationship of citizens with their city. In this context, existing paths and visual connections and historical references are important.

In addition, there are significant strategic places that need special attention, such as the pedestrian zone and the entrance areas of the city. From a climatic point of view, the element of water is particularly well suited due to its positive urban climatic effects as design elements, in particular against the heat island effect. Water also has a high appeal particularly to children, so that the image of the family-friendly city could also find support.

ST E.4 Securing visual connections and orientation points throughout the city

The energetic optimization of neighborhoods will lead to long-term changes in the cityscape and thus also in the orientation system of the city. The focus, therefore, is an approach that ensures important existing visual links and added new landmarks in the urban structure. This can be achieved through “landmarks of the energy and climate change", e.g. "Farm bunkers" or new wind turbines.

The addition of the power plants must be in balance with architectural history, the city skyline and the landscape.

7.2.4.6. ST F: Safeguarding and strengthening of centers and supply structures

For Bottrop, with its low population density, safeguarding and strengthening of centers and supply structures is a goal of particular importance.

It is not only about the inner city, but also functional and attractive additions to centers and accessible neighborhood centers. Not only the everyday comfort in the neighborhoods benefits from shopping and service offerings accessible on foot and by bicycle. In addition, CO_2 emissions are caused by long shopping trips; therefore this emission will be avoided or reduced (the weekly shopping still takes place usually by car). The cover in the Bottrop and in the pilot region is generally satisfactory with the existing neighborhood centers and supplementary attachments. However, in the southern districts - Ebel and Welheimer Mark – there is a gap in the local supply chain and thus the potential for development of further services and increasing the population density.

The Bottrop city center is a diverse living and economic space with high use and building density, which is why measures of climate-friendly urban redevelopment can be particularly efficient, exemplary and influential image here. Taking into account ongoing improvement projects (Hansa center) and strategic objectives (such as from the retail concept), this offers the possibility of climate change mitigation and adaptation measures.

ST F.1 Improve the attractiveness of the inner city core

The Bottrop inner city is the urban core of the InnovationCity. Due to the wide variety of local actors (production companies, service companies, Bottrop municipality, etc.), there is a great opportunity to promote innovation as well as the business climate of downtown. These building-related energy-saving measures, energy concepts, intergenerational public spaces, measures to improve the microclimate and traffic reducing measures can be linked together in a comprehensive and efficient manner and generate synergies to be implemented. Every single energy-efficient and climate-friendly contribution can lead to an improved image of the city and therefore produces a visible and qualitative gain for the city.

ST F.2 Strengthen decentralized supply structures to secure primary services close to residents

A close-knit, nationwide network of local shopping facilities is fundamental for sustainable and climate-friendly urban development. The tiered hierarchical centers in the pilot region are already revealing a good spatial distribution. However, adaptation needs exist in the energy, urban and open space planning and spatial configuration of the objects and spaces. Energy-optimized retail properties, the sustainable use of lesser used areas, unsealing and greening of parking areas, wheelchair accessible places, for example, make a significant contribution to climate-friendly urban redevelopment and the establishment of the consequences of demographic change.

7.2.4.7. ST G: Preservation and development of open spaces

Studies have shown that the pilot region and the city of Bottrop are well laid out with green structure. Only the downtown area has a lack of green spaces. In addition, the peripheral areas of the pilot region are characterized by greater unsealed open areas (agricultural land, etc.). Quality and features of the open spaces are to be assessed differently, taking into account their function and location in the city. It is very important to maintain and strengthen the existing green structures and unsealed open areas because they form the basic framework for the functioning of the ecosystem, species and habitat diversity as well as quality of life.

Conflicts can arise in this case especially in the case of structural compaction, which should be judged carefully case-by-case. The care of the green areas should be better focused on the requirements that are triggered by climate change.

ST G.1 Proper maintenance and climate-friendly development of green areas and open spaces

The preservation of urban green spaces and unsealed open areas (e.g. agricultural land) is of central importance in the context of climate adaptation. Vegetation structures contribute to thermal regulation and to improve the overall climate and air hygiene situation. Considering the terrain morphological conditions, the type of green and open surface and the course of the ventilation lanes, compensations for the effects can be achieved for stressed areas and heat islands as the Bottrop city center. Taking possible consequences of climate change into consideration, this urban climate compensation function is of growing importance. Due to the changing climatic conditions, with an increase in negative climatic situations by heat stress, increase in peri-urban and urban green areas and unsealed open spaces is vital. In addition, the vegetation in peri-urban green areas is under increasing stress by drought, heat and heavy rain. The consequences require a situation-adapted and increased maintenance effort, e.g. more frequent irrigation or pest control. Using of more heat and drought resistant plant species is also recommended.

ST G.2 Create and maintain new green structures, considering the changing climate (i.e. dismantling buildings, unsealing open spaces, greening buildings)

Taking into account the possible consequences of climate change, the creation of new public and private green areas, especially in highly sealed areas such as the downtown, is of particular importance because the urban green structure offers various positive effects on climatic and environmental situation. Unsealing of surfaces leads to an improvement of soil functions, soil water balance and microclimate conditions. If unneeded buildings or other impervious areas, such as roads, parking lots or storage areas shall be dismantled, new green areas may arise.

This applies to both private and public spaces: in housing estates and in the commercial and industrial sector, the unsealing and greening of courtyards, patios and parking lots, etc. are meaningful and purposeful measures. In the public sector climate-sensitive upgrading of urban areas, street areas, car parks and schoolyards provide possible starting points. Building greening, which is of special importance, can achieve positive climatic and energetic effects. The feasibility of appropriate roof and façade greening in particular is the focus of pilot project. New public green spaces should be multifunctional and available in the future, which means that it is important to add the social and ecological aspects to the urban climatic effects and the energetic dimension in planning. Also efficient maintenance and care is essential in public green spaces.

In case of Bottrop, more than 10% of the total surface area is occupied by roads, parking places and paths (1,049ha out of 10,061 ha), which are mostly sealed surfaces (City of Bottrop 2009). Therefore, there is a huge potential for creating unsealed spaces and improve the quality of life, and adaptability to climate change at the same time.

7.2.4.8. ST H: Activating the potential of open spaces: promoting attractiveness and multi-functionality of unsealed open spaces and green spaces

Green and unsealed open areas often offer a variety of ways to optimize different space potential and thus to increase the functionality and attractiveness. There is the possibility of adding contemporary uses to open spaces, based on the existing spatial situations and synergies of the specific site, in order to add value to the area for the people as well as nature and the landscape. Thus, an optimal green space possesses climate regulating functions which serve as conservation of biodiversity, act as a retention area for storm water and serve the neighborhood residents for recreation, communication and contact with nature.

On agricultural lands, which belong to the group of unsealed open spaces, including biomass can be developed as an eco-friendly and useful method, as long as it is in the settlement context. Certain outdoor areas, such as Halden, can often use also ideal for wind energy. The compatibility of uses with each other in this condition needs to be tested.

ST H.1 Improve public and semi-public open and green spaces (i.e., functionality, quality and accessibility)

Public and semi-public open spaces include green spaces and unsealed areas in Bottrop, such as various parks, cemeteries, allotments, sports and playgrounds. Basic conditions for the use of public and semi-public open spaces are their availability and accessibility. The baseline analysis shows that the open spaces in Bottrop in general are easily accessible because they are situated either within the neighborhood- specific settlement areas or immediately adjacent thereto. Accessibility is also given, so the focus is on the spatial distribution of entrances that are granting at best, a good accessibility of the respective adjoining neighborhood areas. Also the creative aspect of the entrance situation is in this context of particular importance, as these are considered the "business card" of the green structure such as a park.

In addition to the availability and accessibility aspects, the facilities and the design quality imply the attractiveness of a green structure. It is important to take into account that different user groups have different claims on design and equipment. Children and young people often search " wilder " green areas and sports (skate parks, etc.). In contrast, older people often prefer areas with higher design level and quality of care and a good condition. Therefore, the functional features, design and furnishing of green areas such as parks and playgrounds, should comply with the possible requirements and potentials of users and local residents. Added to this is the need to consider the effects of open spaces on the urban climate in each case. Playgrounds, which are among the unsealed open areas with appropriate equipment, offer a variety of uses.

The approach to use surfaces as multifunctional may include positive impacts on the quality of stay: for example, integrated solar panels on pergolas can create shaded recreational areas.

ST H.2 Improve private green areas (including open spaces near buildings)

The analysis of the Bottrop pilot area has shown the good network of green, especially the private green spaces and unsealed outdoor areas. Home gardens in older residential areas, which are often very large due to their original function for self-sufficiency, characterize the neighborhood-specific general structure, especially in Batenbrock and Eigen. The private green areas also include greened outdoor spaces in Bottrop commercial areas, which feature different types of greening. Especially in the peripheral areas of the pilot area, there are large agricultural lands and contiguous open space, such as in the Bottrop south. Also agricultural land contributes to the structural diversity. The seasonal change, possibly with appropriate organic farming crop rotation and margins of fields, provide starting points for an increase in leisure and recreational value and to increase urban biodiversity.

At the moment, there is a high potential to increase the utilization and functionality of large private gardens, which are often not fully utilized. The maintenance of these green areas is time consuming and costly, which can be a burden for elderly residents. In agreement with the owners, there is the opportunity to develop parts of these gardens as public green areas during the concession. This allows the quality of living environment for the residents and the neighborhood in general to increase.

ST H.3 Maintain and develop urban-related land-uses

Urban agriculture and urban forestry are among the forms of land use in and on the edge of urban agglomerations. Due to the location of the pilot region in urbanized structure of Bottrop and the associated land use, those two land uses play a rather secondary role (agriculture: about 5.4 %, and forestry 0.8 % of the total area of the pilot area). In addition, there are some small gardens in the study area, which are used by the citizens of the city as allotment gardens.

Basically, agricultural lands and forest-dominated areas are preserved in the context of their ecological and social functions as well as significant components of the open space structure of the urban cultural landscape in the Emscher Landscape Park. There is a significant development potential for an urban agriculture in urban structure of Bottrop, due to the proximity to the consumers or to the city residents. There is already a direct market on site and a weekly market in the city center. Another possibility is the provision of allotment gardens for the urban gardeners on the arable land.

ST H.4 Produce renewable energy in and from green areas

The implementation of this strategy covers all thematic aspects related to the renewable energy and their visualization in space as a design element. These include the production of renewable materials, bio-energy and the use of wind and solar energy.

Based on the specific open space, the combination of different aspects should be tested. In addition, plants can also function as a design element with identity content in the urban space. They can convey a special meaning, visible from the outside, and become a theme for Bottrop for the production of renewable energies.

7.2.4.9. ST I: Networking through preservation and development of open space structures

One task of the RVR[30] is to maintain the regional open space protection and development, considering both qualitative and quantitative aspects. In this context, RVR developed a regional open space concept as informal technical work plan. The aim of the open space concept is the creation of a continuous, graded green structure, with connections to the regional and local landscape, green bodies and the residential settlements boundaries. Linear elements, such as cycling and hiking trails, rail lines and margins of rivers, should construct a networking space, ideally starting from any residential area. This system should provide an attractive chance for the leisure and recreational use, at an accessible position. The implementation of the open space concept for the Ruhr brings about positive contributions to the climate change issues, climate change adaptation and quality of life.

With the stated objectives for the further developing of regional and local open space system, the following thematic aspects are strengthened:

- Networking connects the structures of the ecological bodies and thus promotes urban biodiversity
- The transport of cold and fresh air via ventilation corridors is achieved
- The accessibility of green spaces and the quality of service for leisure and recreational use will be improved.

ST I.1 Preserve and develop road side green structures

Paths and roads represent linear structures, which are particularly suited to close gaps in the local open space system. Cycling, walking and field paths and

[30] Regionalverband Ruhr

service roads depict a good potential for a high-quality networking without increasing emission loads. The existing structures in the regional and local green network provide good starting points for the upgrading of existing deficits. In this context, the creation of new pathways and connections in each case should take into account all the possible conflicts.

ST I.2 Preserve and develop rail side green structures

Due to lack of cross structures, rail lines often provide effective and often largely unencumbered ventilation corridors, which should be preserved and developed. On the disused railway lines, gaps can be closed in the open space system, which also have a positive impact on biodiversity. Consistent and green path connections are also attractive for use by pedestrians and cyclists.

ST I.3 Preserve and develop green structures along the waste water network

Flowing and still waters with accompanying green structure help the species and habitat protection and biodiversity as well as applications for the citizens, such as leisure and recreational use. The Kirchschemmsbach is already in a natural state and therefore serves ecologically and functionally. This creek is an important ventilation corridor in the pilot area and the adjacent paths are well received by the residents. The development of green structures and the creation of stay and rest places with connections to the corresponding settlement areas are desirable.

ST I.4 Preserve the green network of the Emscher landscape park and further develop them

The Regional green structures B and C, of the Emscher Landscape Park in the west and the east of the pilot region, make the connection from the core metropolitan forth in the regional landscape. With reference to the Bottrop pilot area local green connections should be strengthened, so at best, a continuous connection between the landscape open spaces associated to the edge of settlement (e.g. Bottrop South), up to the living quarters is highly preferable.

7.2.4.10. ST J: Restoration and enhancement of natural water balance

Due to the functional and structural changes of the urban landscape in the Ruhr area, opportunities have risen to pursue the renaturation of sewage waters into a natural state. Currently the Emscher conversion is being implemented by the Emscher cooperative. This will have a lasting effect on the pilot region and promote a development towards a naturally networked urban space. The management of groundwater in Bottrop is still required. But it also offers good opportunities to carry out development steps to a natural groundwater regime. It is important here to maintain and secure the groundwater in a sustainable manner, in order to prevent negative consequences on the settlement areas.

ST J.1 Develop artificially made and anthropogenically altered flows and ponds as strong structural elements in the ecosystem

Almost all the rivers in Bottrop are anthropogenic expansions or artificially made due to mining-related changes in the urban landscape. They served in the past as the open discharge of sewage and storm water. With the structural change in the Ruhr area, coupled with the removal of the coal industry, natural conditions for rehabilitation of these water facilities have been created.

ST J.2 Resurrect old water structures and create new natural water basins

Historically, a significantly higher number of open streams were present in the Bottrop city. The aim is to revive these still partially present open watercourses. In some parts, the headwater may not be discharged to the open surface due to unshakeable restrictions. In this situation, spare structures, such as rainwater gutters or more technical design elements can replace the natural ground water. However, these should also be prepared to receive water, for example, for drainage of rainwater from adjacent impervious surfaces.

ST J.3 Enrichment of natural groundwater balance while maintaining the groundwater quality and the efficiency of drainage system

Because of the mining-related industries of the past and the resulting low depths to groundwater in much of the southern area of Bottrop city, today there is a need to derive the groundwater via polder pumping stations in the Emscher.

In order to protect the long-term urban settlement area from potentially damaging ground water rises here, a holistic, sustainable approach to groundwater management is needed. In this case, the measure of the potential groundwater rise will be identified and approaches for maintaining the present drainage comfort, with regard to the groundwater discharge will be developed, while simultaneously safeguarding the groundwater quality is considered. Potentially damaging entries must be excluded in the groundwater.

7.2.4.11. ST K: Development and expansion of a resource-conserving rainwater and wastewater management

The existing drainage system today in the pilot area is predominantly characterized by a combined sewer system, with the common derivation of clean rainwater and wastewater within a duct system. At the end of the sewer system is the Bottrop sewage treatment plant, cleaning the wastewater from this system. Due to the combined sewer, large amounts of water, which actually does not need treatment, undergo energetically costly treatment process, especially in rainfall. The decoupling of clean water from the wastewater system, on one hand leads to a direct energy saving on the treatment plant, and on the other hand is done by separate drainage, seepage and use of the accumulated rain water, therefore enriching the natural water cycle in urban areas.

In particular, the sewage disposal system, consisting of canals, pumping stations and the treatment plant has a high energy demand. An optimization of the existing systems in technical terms has a direct impact on the CO_2 balance.

ST K.1 Separation of dirty and clean water discharge

For decoupling of rainwater streams from the wastewater system, optimally separated sewer systems, parallel guided storm sewers and drainage channels are needed. With the redevelopment of commercial and residential areas, the construction of a separation system is now state of the art. Within the existing combined sewer network in Bottrop, the replacement of the sewer system by a separate sewer system is extremely complex and difficult to realize. The additional construction of a rainwater collection channel that opens into a body of water can be a favorable option under certain conditions.

ST K.2 Development and promotion of measures for decentralized rainwater treatment

Measures of decentralized storm water management are already designed and implemented within the framework of the InnovationCity Bottrop project. These are measures where the storm water runoff from impervious surfaces is brought locally to the partial evaporation or seepage or directed to discharge into a body of water. Today, these water flows are derived for the most part in the combined sewer system.

ST K.3 Energetic optimization of drainage infrastructure

The operation of the municipal drainage network requires energy-intensive machinery. Especially in pumping stations, according to the dimensions of the installed machinery and reservoir volume, pumps must be continually running. In order to optimize the energy consumption in the drainage network, modern technology should be put into practice. Outdated pump technology leads to increased energy use.

In addition, storage potential throughout an urban sewer system can cause temporary relief of the pumping stations, unless they are specifically activated. For this purpose, control models need to be developed for the sewer system. A discontinuous operation of the pumping stations can bring cost savings, for example, by a larger portion of the pump operation relocated to economically favorable evening and night hours or during periods of high production share of renewable energies.

7.2.4.12. ST L: Development and implementation of a water sensitive urban development

The ongoing climate change is ever increasing demands of modern urban society. The previously observed and also further strengthened forecasted climate trends, such as the increased presence of summer heat waves, increase of rainfall as a whole and shifts in the patterns of precipitation and the increased occurrence of extreme events (extreme heavy rainfall and heat waves) require adaptation strategies. The federal government and the state of NRW have already initiated this strategic process.

Even at the local level, an anticipatory strategy needs to be developed for this purpose. Extreme weather events have been almost entirely neglected in the city hydrological context, as well as in land use planning and road design. However a consciousness shift has taken place in recent years. In particular through measures of urban and land use planning, in terms of a "Water Sensitive Urban Development", precautionary flood protection has been considered.

In addition to the implementation-oriented analysis of Bottrop city landscape, sensitization of the population for the theme of "water" is desirable. The creative integration of water elements in urban planning and design, in terms of a sensitive and economical use of the good "water" leads to an increased acceptance of environmentally-and water-sensitive urban development in the population.

ST L.1 Convey the consequences of climate change on urban structures and integrate climate adaptation measures into overall planning concepts

Extreme weather events generally constitute a hazard for infrastructure and urban areas. Extreme precipitation events in the Ruhr area were a tangible reality in recent years. Unavoidable consequences of climate change are therefore to be feared also in Bottrop. Ensuring adequate flood protection in changing climatic conditions is primarily the responsibility of the operator of the drainage systems.

Thus the achievable level of protection is limited and there remains a risk of overload in the very heavy rain events. The risk in heavy rain is controlled with reinforced overflow controls in water. However extreme drought is also an important input in the development of a local adaptation strategy. Risk reduction should be generated in terms of citywide task scheduling options and activities.

ST L.2 Learning with water - environmental education for children and adults

The knowledge available via natural connections about a nature-friendly land use and the Influences of the urban society on natural cycles can raise awareness simultaneously in children and adolescents for their own use of natural resources. The targeted and gentle conditioning of "natural trails" to the water and the integration of water elements in playgrounds can improve this process.

In the context of consumer advice and suggestions, knowledge can be communicated as a water-saving lifestyle, implemented through changes in household behavior and also by technical measures. At the same time this will be made clear that monetary benefits may arise for the individual. These include the possibilities of rainwater decoupling and thus saving on wastewater fees as well as the possible use of rainwater in the house.

ST L.3 Designing with Water - Upgrading of urban structures

In the built environment, the water element is underrepresented. Through design measures, the city can be enhanced by, for example, reactivating existing wells chambers, installing drinking fountains or design objects implemented for visualization of water in urban areas. Open storm sewers, even in urban areas, at the same time can be invigorating elements of urban design and contribute to storm water separation. It is important to take energy saving into account while installing equipment as possible. The installation of photovoltaic systems in the vicinity of plants can act as a kind of energetic balancing measure.

7.2.4.13. ST M: Further embed climate-conscious urban redevelopment in municipal planning and management

The actions of the city of Bottrop are exemplary in energy efficiency, climate change mitigation and adaptation in many ways. Bottrop possesses an integrated climate protection concept, a comprehensive environmental master plan and is very serious with energy savings in urban environment.

Since 1993, when Energy Management was introduced, the City should submit an annual energy report. For the period of 1993-2010, the city saved nearly 21 million euros on heating costs and more than 6.5 million euros on normal power. On the emission side, the city avoided 127 thousand tons of CO_2 emissions. Bottrop received the gold European Energy Award in 2010.

The city's approach is to consider integrated urban and environmental planning projects and processes and to support it by a geographical information system. The GIS covers detailed inventories, such as the solar cadaster and building types, therefore it can be used for sound planning with consideration of climate change mitigation and adaptation needs.

The city of Bottrop is actively involved in achieving and realizing the goals of InnovationCity Ruhr. Despite the achievements, it is important for the InnovationCity Bottrop to continue the efforts to make climate-friendly urban redevelopment firmly anchored in everyday governance and planning in all projects target.

ST M.1 Activation and planning of InnovationCity Ruhr I Model City Bottrop with regional actors and planners

The city of Bottrop is actively involved in regional planning processes, such as in the preparation of the master plan for the urban region Ruhr (Ruhr 2030), participating with the 11 urban districts of the Ruhr. The city is also involved in networks like Dynaklim, which is focused on the future prospects of the Hydrogen network, and Future Cities, the European network of cities to adapt to climate change.

The chance of the InnovationCity Bottrop to give impetus to the regional networks and to receive pulses for the climate-friendly urban development should be used consistently. Approaches such as joint reflection with Essen, on the future of the mining areas in the south Bottrop shows that the city is on the right direction.

ST M.2 Use planning tools intelligently and with consideration of goals for climate protection in Bottrop

The housing stock in Bottrop included in 2010 more than 56 thousand apartments, since 2005, an average of 242 homes were built every year. This makes it clear that the important planning instruments in InnovationCity should focus on rebuilding the stock.

It is advisable to make the energy efficient residential construction in sustainable neighborhoods, the subject of urban planning policies for which arrangements can be negotiated with respect to the use of renewable energies, roof greening, building standards, open space design, alternative mobility concepts and etc.

For the climate-conscious urban redevelopment, there are informal planning instruments such as the establishment of integrated urban development concepts for a designated urban renewal area. This step has already been completed for the InnovationCity pilot region. In addition, it should be investigated on whether and how this can be intertwined with urban development or redevelopment activities.

By these activities, the conditions for the use of certain modernization programs will arise (such as those of the NRW Bank), with which the city can help Bottrop citizens as they improve their apartments and houses to achieve a more energy-sufficient neighborhood. This should be accompanied by personalized counseling, with a neighborhood architect or an energy consultant.

7.2.5. Sample Project

In order to explain the connection between the mentioned strategies and the proposed projects, a sample project recommended by the Master Plan is introduced here. This project is the "Street Planting" and aims to add more green plants to the streets of the pilot region. The target group of this project is the residents and visitors of Bottrop.

Based on the analyses already performed in Bottrop, some streets have been selected for further enrichment with urban greenery, through planting more trees and shrubs along them. These streets have been assigned with the highest priority on the greening list.

In addition to improving the microclimate, the streetscape greening also provides some synergies. Due to the linear arrangement, street trees represent network structures that are both for the protection of species and also ideal for residents. Street trees and shading techniques employed lead to a revaluation of road space, therefore the pedestrians' and cyclists' appeal to use these connection paths increases everyday.

Figure 61: Streets with high priority for tree planting (Source: (ARGE IC Ruhr 2013))

This project is designed according to the strategies "ST G.2: Create and maintain new green structures" and "ST I.1: Preserve and develop roadside green structures".

7.3. The German strategy toolbox

In previous sections, two separate projects were reviewed. In the strategies proposed in both projects, there are similarities in the points of focus. These focal points are the areas, which need more immediate attention. However, in each project, there are some unique aspects that are ignored in the other one. Based on these projects and proposals, the adaptation and mitigation strategies in the Ruhr can be summarized as the following:

- Improved urban ventilation
- Connection of green belts (green axes of development)
- Unsealing spaces
- Creating open spaces, parks, etc.
- Greening: Streets, roofs, façades, inner blocks
- Bringing water to the city: Ponds, channels, fountains, artificial irrigation
- Building orientation
- Thermal insulation
- Provision of shadow: on buildings, sidewalks
- Improved urban materials: Asphalt, construction materials
- Densification and de-densification
- Re-use of space: infills, brownfields
- Land use alteration: Mixed use, multi-functional

- Promoting urban identity: Landmark, etc.
- Water management
- Energy conservation
- Renewable energy production
- Educating and informing people and governments
- Change in lifestyle: Energy and water conservation
- Integration of climate in the planning paradigm

The applicability of these strategies to the Iranian semi-arid context and their performance in this certain situation are investigated in the following chapters.

Chapter 8: Analysis and Results III

8. Microclimate Simulations

Based on results of the in-depth analysis of the Iranian traditional climate regulating mechanisms (Chapter 6) and the German adaptation and mitigation projects in the Ruhr (Chapter 7), it was decided to explore the effects of seven urban features on human thermal comfort through microclimate simulations in Iran. Two of these urban features relate to the construction materials used in the urban fabric: Conductivity and Reflectivity. Street network orientation, the height and width ratio of streets, extension of buildings into the public street for casting shadows (balconies), presence of vegetation and the configuration of the building within the land plot are other variables investigated in this study.

8.1. Model details

Grounded on the literature review and to fulfill the aims of the research, the properties of the model were decided. The main objective of these simulations is to investigate the effects of several urban factors on the thermal comfort in the streets. For every factor, a base alternative was selected as a reference point, and other alternatives were developed to focus on a certain urban intervention.

Three sets of receptors[31] were used in every model: one in the middle of the street to provide an idea about the average situation during the day

[31] Receptors are selected points inside the model area, where processes in the atmosphere and the soil are monitored in detail (Bruse 2009).

throughout the street, and two on the sidewalks, one on each side, to provide data on thermal comfort of specific pedestrian pathways.

Similar to the preliminary model, the models were run for 14 hours, starting from 6:00 am, a time span that captures most of the outdoor activities, which maybe affected by the thermal situation.

One of the properties (short comings?) of ENVI-Met is that you can only manage the initial input values and for the whole simulation no alteration can be made. For example, when simulations are started with a certain wind direction value, there is no way to correct it over the course of day. Since this wind direction changes over the day and although the real world values were available, it was decided to assume the worst-case scenario (the slowest wind in the urban corridor) for these simulations. Therefore in all simulations the wind direction was feigned perpendicular to the street canyon.

In selection of analysis parameters, one variable was omitted intentionally, and that was the presence of water bodies in urban areas. The reason behind this delimitation lies on the results of similar studies. It is already established that water basins have a very limited domain, in terms of their effectiveness on the thermal situation around them. The latest research in this field is by Fröhlich and Matzarakis (2013), which showed that water basins do not demonstrate any effect on thermal bioclimate beyond their borders.

The investigated criteria were as follows:

8.1.1. H/W ratio

The ratio between buildings' height and street width is discussed in literature as a prominent factor, effective on the thermal comfort, especially in hot and arid climates. Generally, a higher H/W ratio is perceived to provide more thermal comfort, mainly because more parts of the street are within the shadows cast by the buildings, and for a longer period of time.

Traditionally, alleys and streets in cities with hot and arid climates were narrow and the buildings were high. This type of street network is not limited to Iran, and is visible in other countries as well. But with the introduction of automobile to cities, street networks had to widen in order to accommodate them. Ever since, automobile access is a main criterion in street profile design.

For financial reasons, developers want to build as high as possible, with the maximum number of flats per land slot. However, urban design guidelines have specific values for the maximum height of buildings. These limitations mainly depend on the width of the adjoining streets and are foreseen in the comprehensive plans.

In this study four alternatives of H/W ratio have been analyzed, both in North-South direction and East-West. At the moment the highest allowed H/W ratio in Kerman is 2 (refer to chapter 5). This ratio was selected as the base configuration for the following simulations. At this stage the analysis covered very low ratios (H/W=0.5) to rather high ratios (H/W=4).

In these models, the width of the street was kept at a constant 8 meters, a rather common width in this context. At this point, buildings' height was the variable, and was set to, 4, 8, 16 and 32 meters respectively.

The urban regulation in Iran, generally require buildings to occupy the northern parts of the land plot and a private courtyard in south. Therefore, in east-west streets in residential quarters, walls between public streets and private courtyards establish the northern side of the street. These walls are around 3 meters high, on average. In some cases it is allowed to construct a small room, mainly for storage or even an extra bathroom, but these structures never exceed three meters in height. Figure 62 demonstrates a typical section of a neighborhood in Kerman. The rotation in the street grid (30 degrees) and small structures at the south end of the plots are noticeable.

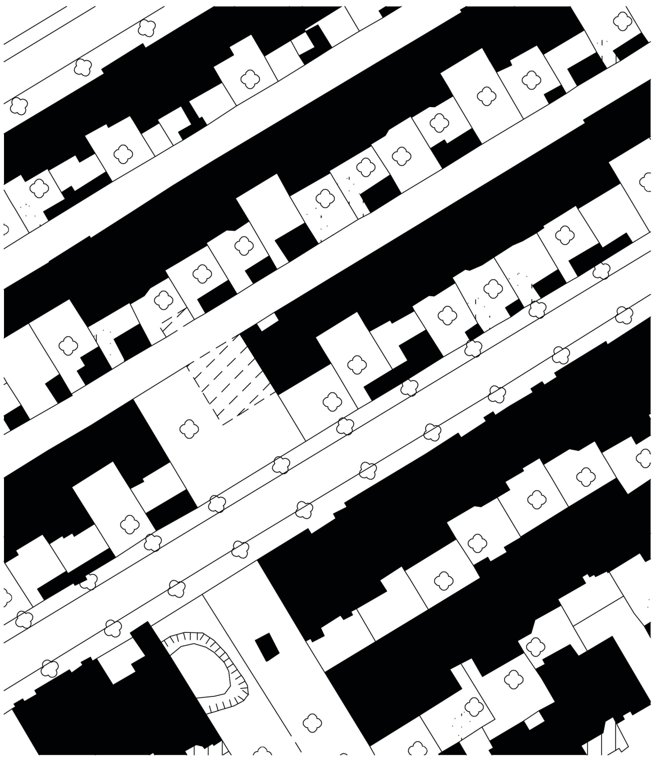

Figure 62: Plan of a typical neighborhood section

This phenomenon leads to an asymmetric street profile. In similar studies in contexts where the buildings' height was not even through out the street, the H/W ration has been defined as the *Average* ratio of heights to street width. However, in this study, it was decided to define this value as the ratio of the *Maximum* height to street width.

In these simulations, for East-West streets, the southern part (building) had a variable height, while the northern part (courtyard wall) had a constant height of 3 meters. In Figure 63: Eastward street profile is depicted as it is modeled. In this case, the values have been assumed as H=16m, W=8m, and h=3m, therefore the H/W ratio would be 2. Figure 64 demonstrates the variables used in this parametric models.

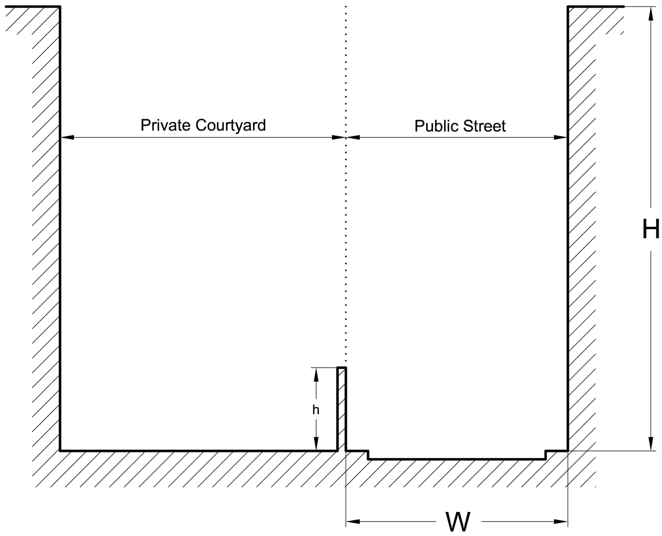

Figure 63: Eastward street profile

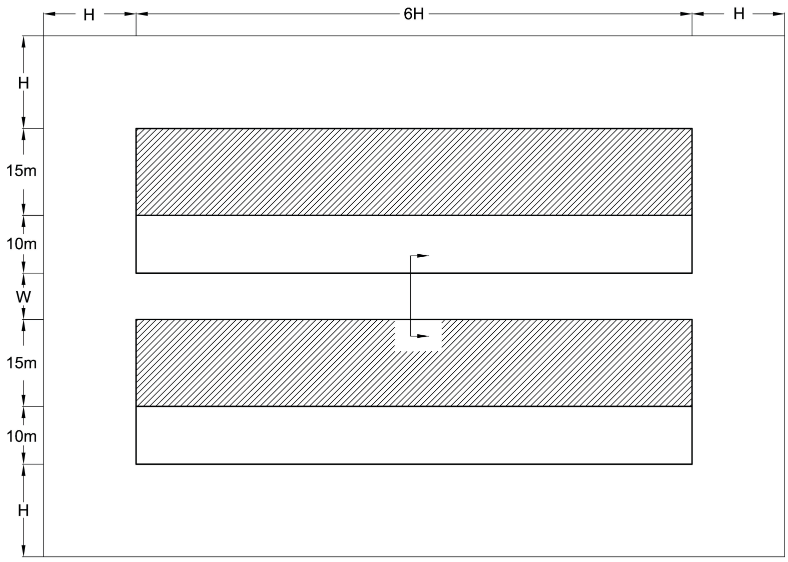

Figure 64: Plan view of modeled area

8.1.2. Orientation

Considering thermal comfort, the orientation of the street network in relation to the patterns of sun movement and prevailing winds is an important issue. In traditional Iranian urbanism, there was no master plan for the city. Every single building was designed based on the needs and fiscal situation of the owner of the property. Thus, the streets and alleys were formed organically, in a way to minimize the negative impacts of the climate and improve passive solar energy adoption. While in western countries, mostly American urbanism, street networks are planned according to due geographical directions.

In Kerman, the street network pattern is tilted approximately 30° counter clockwise. By this rotation, during winter, solar radiation would penetrate more into buildings, minimizing the overall energy consumption. However, the effect of this rotation on thermal comfort at the pedestrian level had never been studied.

At this stage of the analysis, two sets of models were developed for North-South and East-West streets, each consisting of two models: one tilted and one straightly parallel to meridians and latitude lines (refer to Figure 65: Modeled orientations).

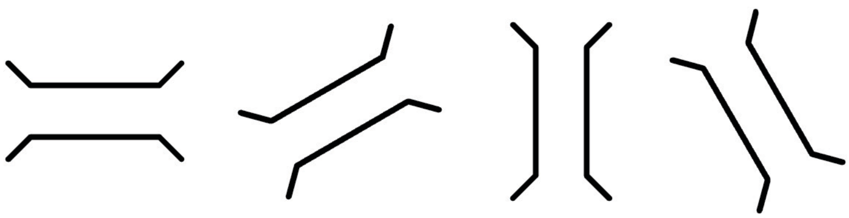

Figure 65: Modeled orientations

8.1.3. Reflectivity

The properties of the materials used in urban environment have tangible effects on the local microclimate. In this research, materials were studied in two separate aspects: first, by the reflectivity of the urban surfaces (roofs and walls) and then, by the thermal conductivity of these materials. In terms of reflectivity, three scenarios were investigated: one with a very low reflectivity (Concrete for both ground and façades), one with a rather medium reflectivity (Normal brick for walls and asphalt for ground), and one with high reflectivity (Light color painted façades and dry soil ground). Materials with medium reflectivity have been selected as the reference point, for other simulations.

Table 12: Surface reflectivity

Scenarios	Low	Base	High
Façade material	Concrete	Normal brick	Light color paint
Façade reflectivity	0.1	0.3	0.5
Ground material	Concrete	Asphalt	Dry soil
Ground reflectivity	0.1	0.2	0.35

8.1.4. Conductivity

The relationship between thermal conductivity and human thermal comfort outdoors was analyzed in three groups. For the first group, materials with low thermal conductivity were assumed, such as normal brick. The second scenario was concrete, which has a medium conductivity, and the last one was dense brick with high values of thermal conductivity. In this research, the material of building roofs' was assumed as a constant.

As normal brick is the conventional building material used in the majority of structures in the focus area, this material was selected as the base value for further simulations.

Table 13: Material thermal conductivity

Scenario	Base	Medium	High
Material	Normal brick	Concrete	Dense brick
Thermal conductivity	0.7 W/m°C	1.2 W/m°C	1.6 W/m°C

8.1.5. Plot coverage

As discussed before, there are certain limitations for the location of a building within its land plot and the percentage of the plot that it covers.

In the early stages of the research, several configurations were developed for further analysis in the simulation phase, but eventually two of them were selected, as the others had issues with privacy and were against many national urban regulations. One of the two alternatives was the current situation[32], which was selected as the base case, and the other one was with the buildings adjacent to the street on both sides. This means that in the plots on the northern side of the street, the buildings would occupy the southern side of the land plot and the

[32] In the Iranian culture of architecture and urbanism, the plots on the northern side of a street are known as a *Northern House*, in which the main entrance is from the street into the private courtyard, while buildings on the other side of the street are called *Southern Houses*, where the main entrance is directly into the building.

private courtyard would be in the north. Figure 66 shows how this alternative has been modeled in the ENVI-met environment. The location of the receptors in relation to the street canyon is also depicted. It should be noted that this analysis does not apply to the North-South streets.

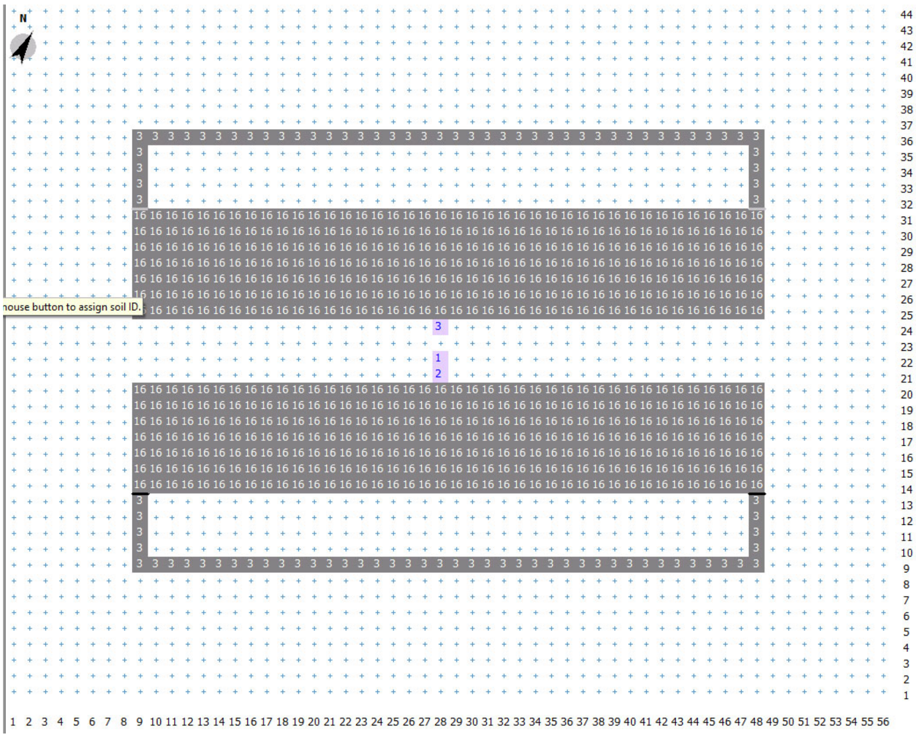

Figure 66: ENVI-met model of street-side building configuration

8.1.6. Balconies

Provision of shadow is a main strategy in improving the outdoor thermal comfort in hot and arid cities. This can be achieved by balconies, colonnades, pergolas and installation of other devices that offer shadows on the public realm, especially on the pedestrian pathways.

At the moments, urban codes put very strict limitations on the design and implementation of any private structure that may enter the public grounds, even the balconies as they extend outside of the land plot into the street. These limitations are both in terms of the extension into the street and their minimum height, and it all depends on the width of the street. Current regulations have been discussed in detail in chapter five.

In this part of the investigation, the effect of balconies was studied in two steps. One alternative was without any balconies, and the other one was with balconies extending 2 meters into the street, at the height of 3 meters on both sides of the pathway. In this case, the receptors were placed under the balcony.

8.1.7. Vegetation

Vegetation and green infrastructure of a city also have been discussed as effective factors in the world of outdoor thermal comfort. Trees help the city breath. The transpiration of a tree cools down the air temperature and increases air humidity. However, in streets with high car traffic, a line of trees with large canopies may create another problem. The particulates produced by automobiles will get trapped under the canopies, creating a layer of very low quality and polluted atmosphere at the pedestrian level.

Urban vegetation can have several forms: they can be parks with various sizes, tree lines along streets or even green façades and roofs. In the hot and dry climate, it is not that easy to implement a green infrastructure across the city, as the vegetation needs constant care.

In Kerman, the per capita amount of green spaces is very low. In most streets, there are water canals (which are only used in rainfall management and irrigation of trees) on one or both sides of the street. These canals are usually 80-120 cm wide and 40-80 cm deep. Figure 67 outlines a profile of a typical street in Kerman, with sidewalks and water canals on both sides.

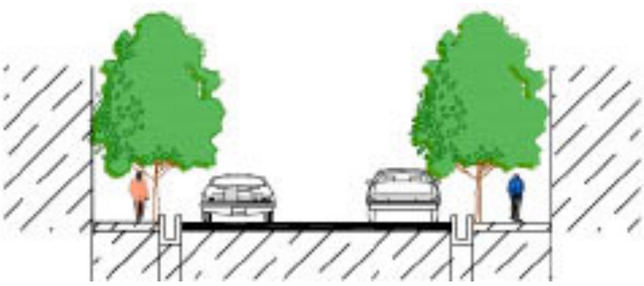

Figure 67: Profile of a typical street with water canals

In most areas of this city, urban vegetation consists of sparse trees. In main streets, the municipality takes care of the trees and there is even grass grown on the boulevard islands, however, in secondary streets local residents are technically in charge of the trees grown in front of their properties. Two models were developed for this section, one without any vegetation, and one with two rows of medium size trees along the street.

8.2. Microclimate simulation results

As mentioned before, the ENVI-Met simulation results were exported to Rayman to calculate PET. ENVI-Met is capable of calculating many environmental values, but in this research only a part of these results were used: Temperature, Relative humidity, wind speed and Mean Radiant Temperature (T_{mrt}). Apart from these values, Rayman needs some other input data, some concerning the geographical location of case study and some related to the subject of the experiment (physical situation and activities). It also needs the Sky View Factor (SVF) but since it was already accounted for in the calculations of T_{mrt} in ENVI-Met, it was assumed as 1.

In order to compare these alternatives, the average PET values between 6:00 am and 20:00 pm were calculated.

The results are as follows:

H/W ratio

In this study, the daytime temperature was found to be higher in east-west oriented canyons, because these streets receive solar radiation during a longer period of the day.

Daytime PET values, calculated at pedestrian level (at 1.5 m height) for three sets of receptors are shown in Figure 68, Figure 69, and Figure 70. These charts demonstrate how PET changes throughout the day, for different H/W ratios in East-West streets. The Middle Receptor, which represents the average trends of PET, shows that generally speaking higher H/W ratios lead to lower (in this case more comfortable) PET values. For example, when the H/W ratio is at 0.5 (the width of the street is two times in comparison to the height of the buildings), for 12 hours per day, the PET value is more than the upper discomfort limit (33°C), but for a deeper canyon, when H/W ratio is at 4, PET value exceeds this discomfort limit in just 5.5 hours.

However, during the hottest hours and when solar radiation is at its peak, the H/W ratio does not play a significant role and all the PET values for different scenarios are almost identical.

In two of the alternatives (H/W=0.5 and 1), the PET has two peaks during the study period, one at around 10:00 h and the other one at 16:00. At these times, the sun is positioned due-east and due-west respectively and therefore the entire street canyon is exposed to solar radiation.

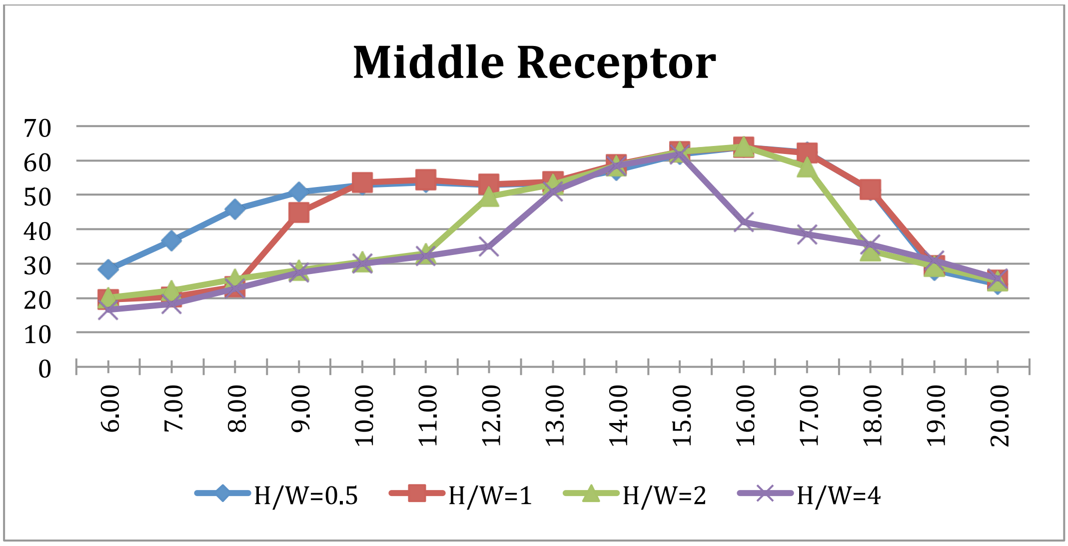

Figure 68: PET values for various H/W ratios throughout the day in the middle of an East –West Street

On the southern sidewalk, the effect of H/W ratio on PET seems to be negligible until 16:00 h. the only difference is that, in streets with deeper canyons, PET drops faster and sooner. In this side of the street, the PET is within the comfort range, before noon.

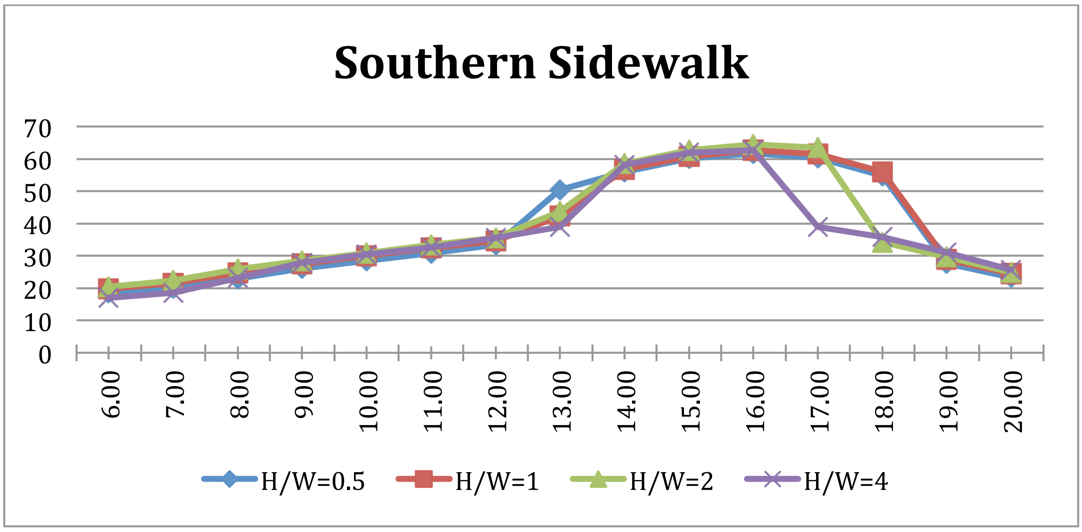

Figure 69: PET values for various H/W ratios throughout the day in Southern Sidewalk of an East – West Street

However, on the northern sidewalks, PET is affected dramatically by the H/W ratio. For ratios smaller than 1, the differences are still negligible. After 17:00 h, PET follows the same pattern for all configurations and drops at the same rate.

All in all, it can be concluded that in East-West street canyons, climate conditions can be considered as comfortable in southern sidewalks before noon, and in northern sidewalks in the afternoon after 17:00 h.

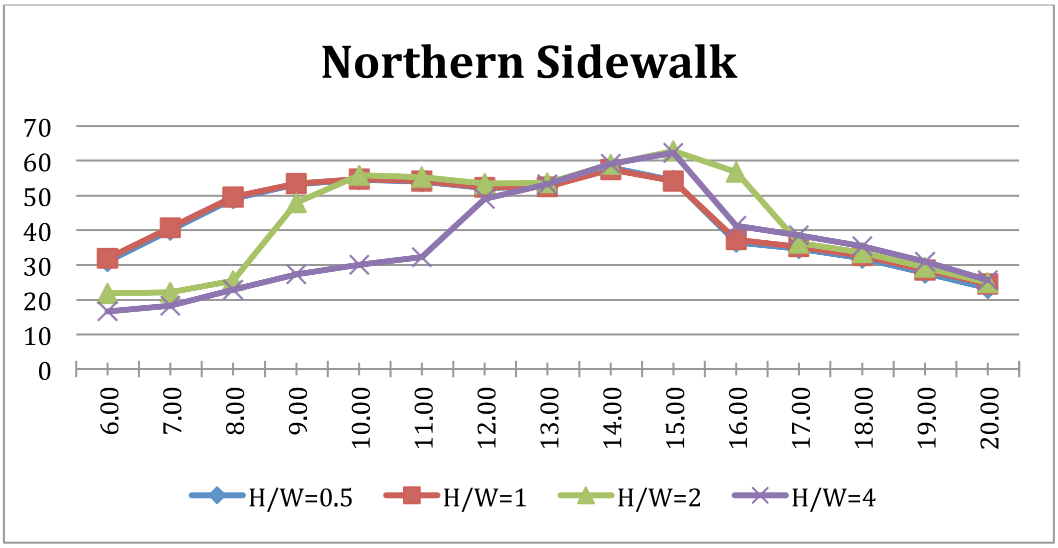

Figure 70: PET values for various H/W ratios throughout the day in Northern Sidewalk of an East – West Street

Table 14 shows the average PET value for the whole study period. Again, the reverse relationship between H/W ratio and PET is observable.

Table 14: Average PET values for East-West streets for different H/W ratios

Receptors	H/W=0.5	H/W=1	H/W=2	H/W=4
Middle	48.21	45.09	39.53	35.10
South	38.29	38.91	38.55	35.88
North	43.51	43.95	43.29	36.18

In North-South street canyons, the same trend is visible in PET fluctuations during the day, and streets with lower ratio tend to have higher PET values for longer periods.

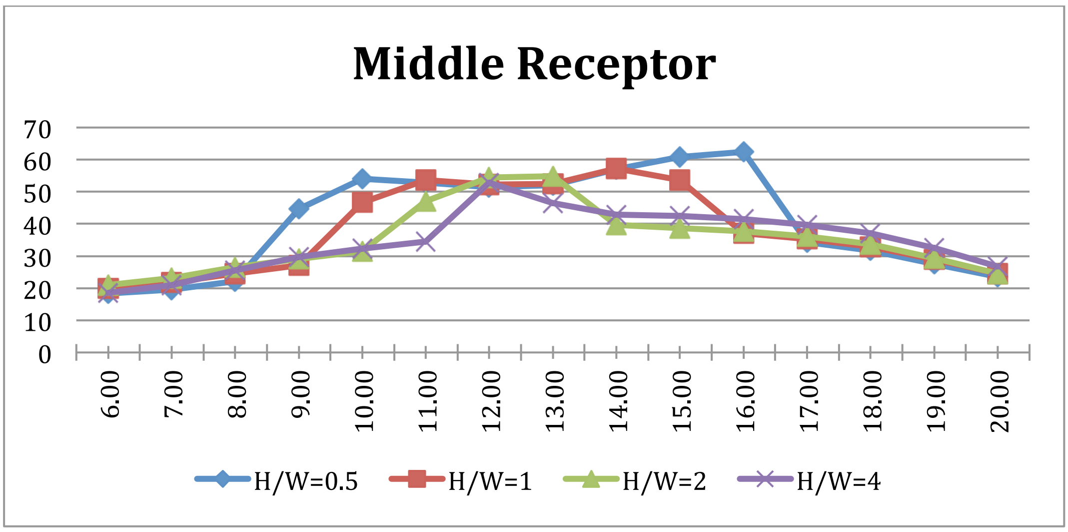

Figure 71: PET values for various H/W ratios throughout the day in the middle of a North-South Street

As the western sidewalks receive direct solar radiations during the morning hours, thermal comfort is at a lower level at these hours in comparison to the afternoon. The rate, at which the thermal comfort deteriorates, is relative to the H/W ratio (Figure 72). However, in all H/W configurations, PET drops at the same rate.

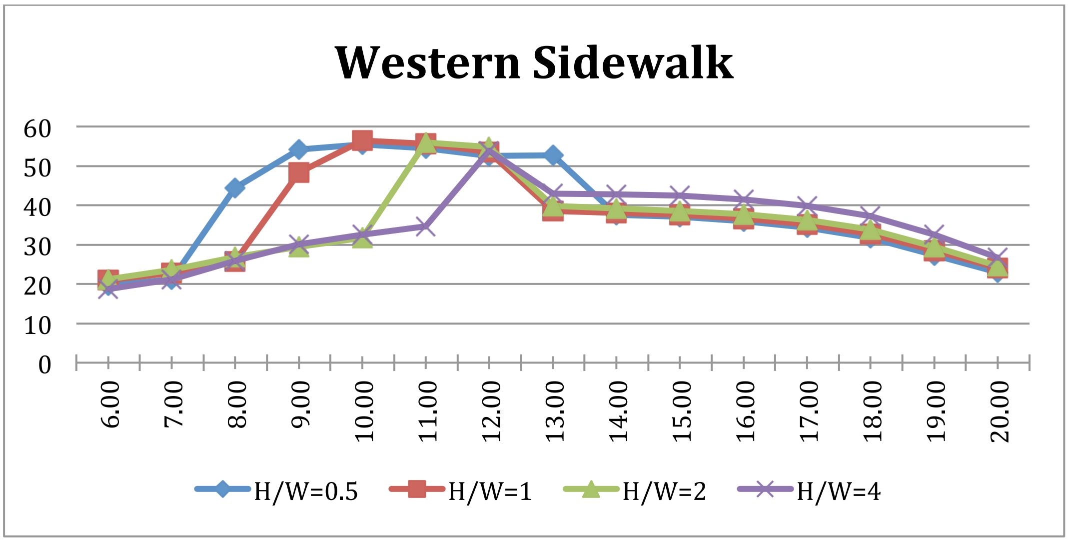

Figure 72: PET values for various H/W ratios throughout the day in Western Sidewalk of a North-South Street

The opposite is valid for the eastern sidewalks. Since there is no direct solar radiation on this side of the street, PET gradually increases at the same pace, no matter how deep or shallow the canyon is (Figure 73). But in the afternoon hours, H/W plays a significant role on the thermal comfort. The deeper the canyon is, the less direct radiation will infiltrate into it, and therefore thermal situation will be in comfortable zone for longer periods.

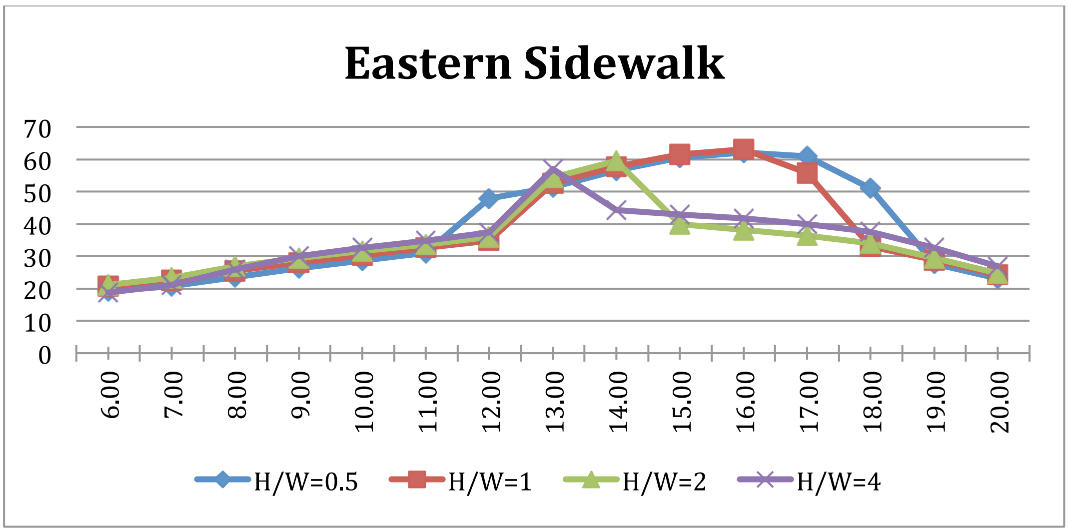

Figure 73: PET values for various H/W ratios throughout the day in Eastern Sidewalk of a North-South Street

Table 15 shows the average daytime PET values in North-South oriented street canyons, in relation to different configurations of street width. Similar to the previous case, thermal comfort improves with higher H/W ratios. Generally speaking, in these streets, thermal comfort on the eastern sidewalks is in a comfortable range before 12:00 h and on the other side of the street, it gradually becomes more comfortable after 13:00 h, nonetheless it is still higher than the upper comfort limit until 18:00 h.

Table 15: Average PET values for North-South streets for different H/W ratios

Receptors	H/W=0.5	H/W=1	H/W=2	H/W=4
Middle	40.85	37.87	35.15	34.93
West	38.77	36.95	34.87	34.86
East	39.36	38.07	34.55	34.89

Orientation

Rotation in the street grid, not only improves energy consumption within buildings; but also has a significant effect on the thermal comfort, at the pedestrian level, in the streets. The simulations show that in east-west canyons, a 30° rotation leads to a better thermal comfort situation, in morning hours and after the peak radiation hours (Figure 74).

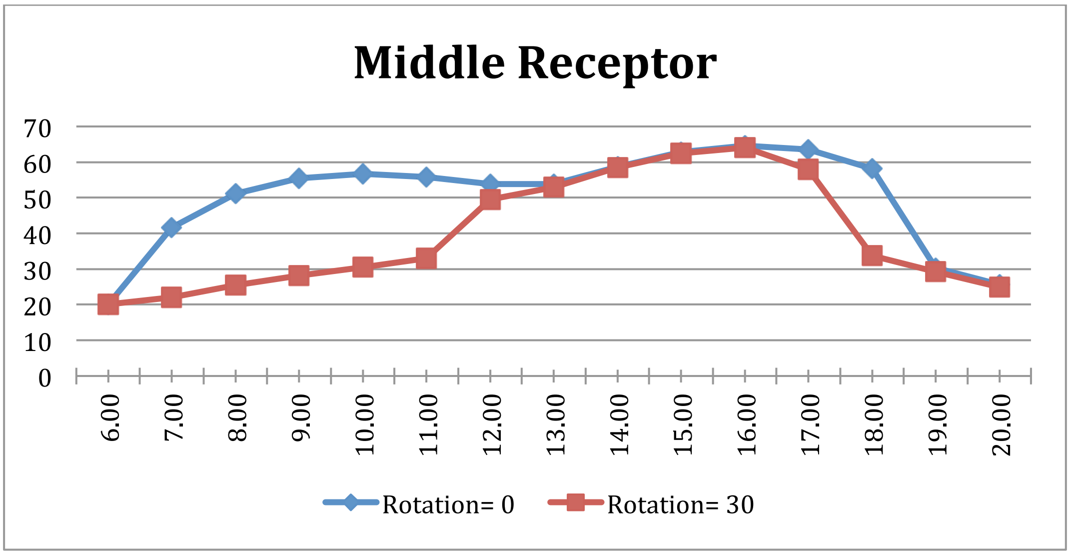

Figure 74: PET values for Rotated and Straight grid alternatives, East-West Street, Middle Receptor

In southern sidewalks (Figure 75), a tilted grid, results in a much more significant change in thermal comfort, in comparison to the northern sidewalks (Figure 76), where this difference is almost negligible.

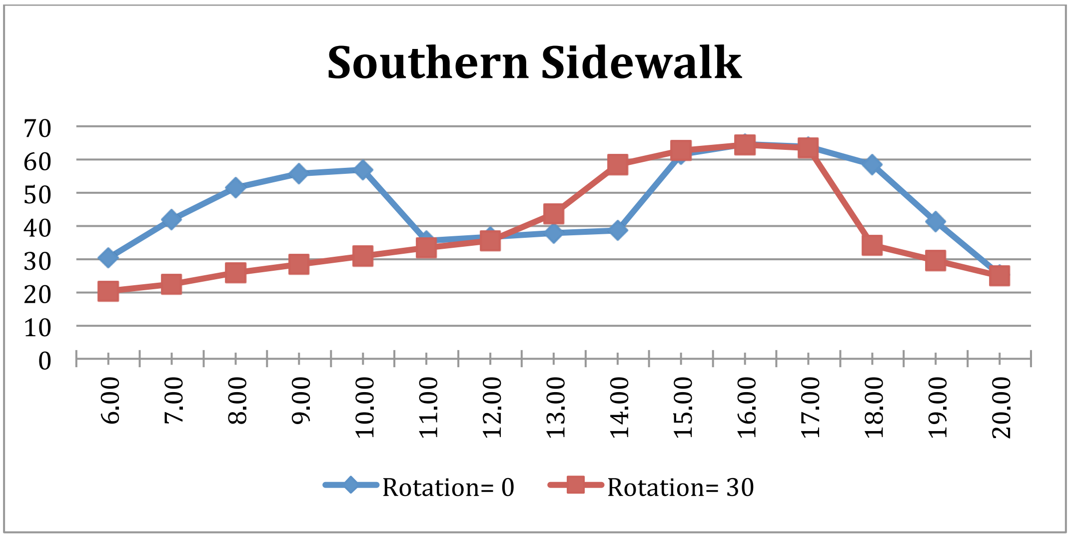

Figure 75: PET values for Rotated and Straight grid alternatives, East-West Street, Southern Sidewalk

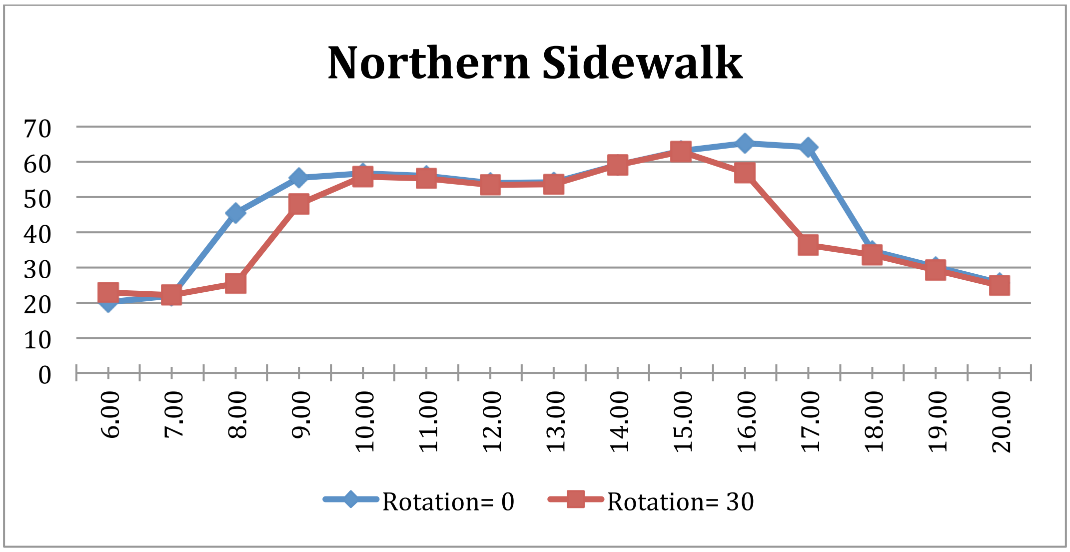

Figure 76: PET values for Rotated and Straight grid alternatives, East-West Street, Northern Sidewalk

The average daytime PET values (Table 16) demonstrates the fact, that this rotation in the grid will reduce the average PET for more than 10° over the course of the day. However, as mentioned before, thermal comfort on the northern sidewalks is affected far less (almost 4°) in this situation.

Table 16: Average PET values for East-West streets rotation

Receptors	Grid rotation= 0°	Grid Rotation= 30°
Middle	50.17	39.53
South	46.70	38.55
North	47.03	43.29

In case of North-South oriented canyons, a rotation in urban street network does not affect thermal comfort significantly. In fact, canyons oriented directly to due-north, have a slightly better thermal situation (Figure 77).

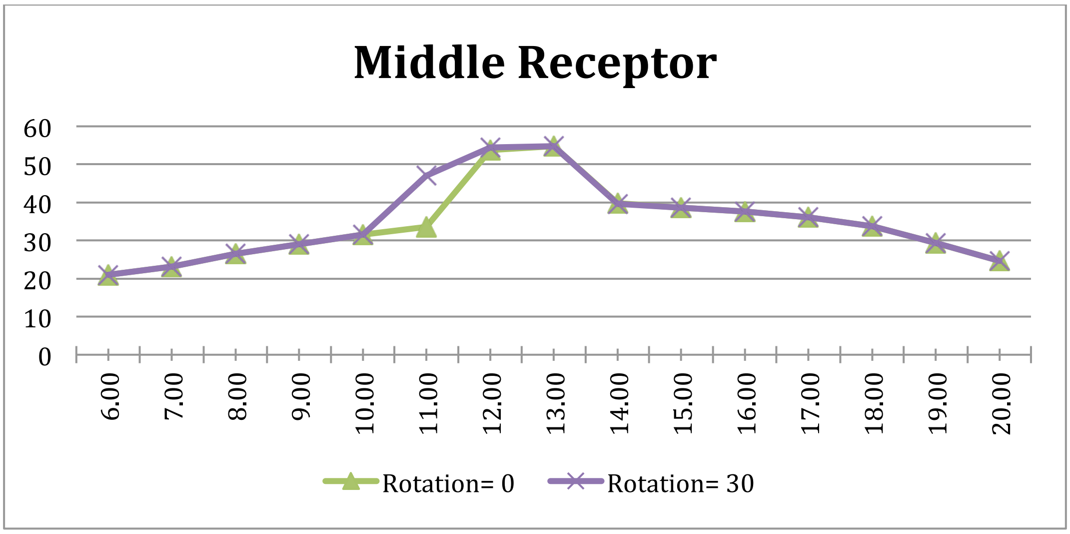

Figure 77: PET values for Rotated and Straight grid alternatives, North-South Street, Middle Receptor

In western sidewalks (Figure 78), the only difference that a rotation makes is a change in the heating and cooling pattern of the street atmosphere. The maximum PET value is the same, but in a tilted canyon, PET rises and drops faster than a street that is not rotated.

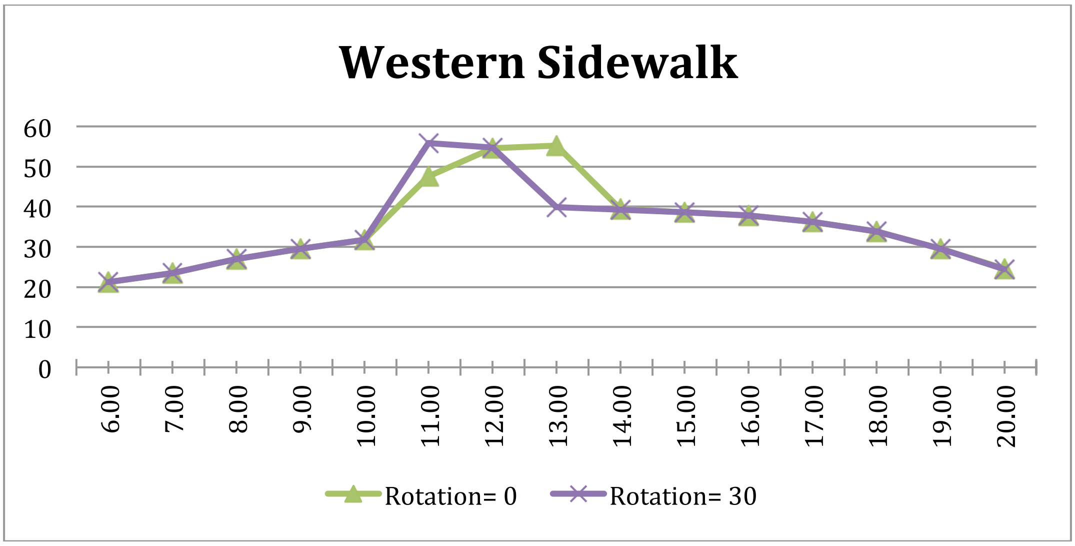

Figure 78: PET values for Rotated and Straight grid alternatives, North-South Street, Western Sidewalk

In case of eastern sidewalks (Figure 79), PET values are almost identical in both scenarios, and a rotation at this range (0° to 30°) does not have a tangible effect on the thermal comfort.

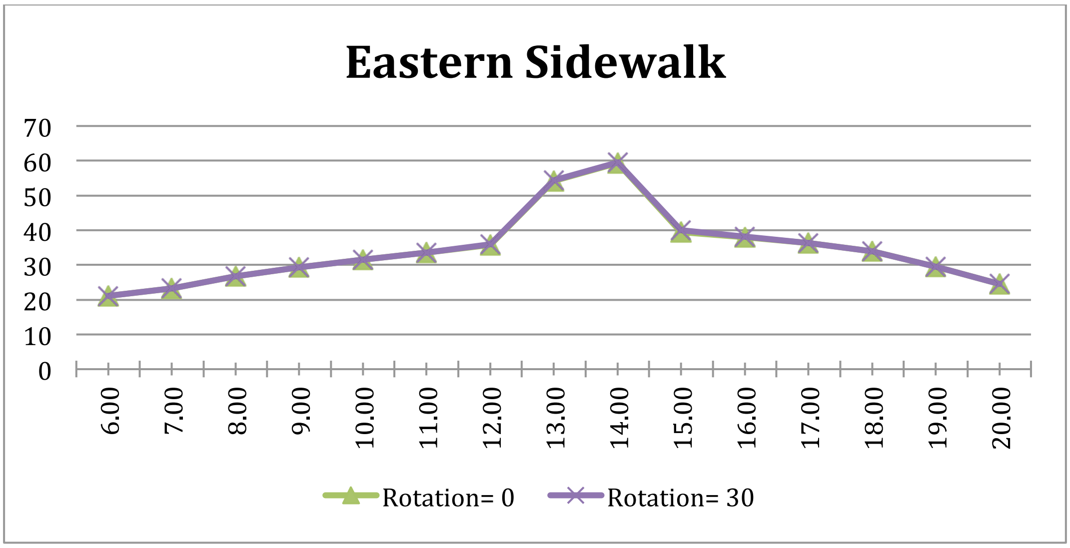

Figure 79: PET values for Rotated and Straight grid alternatives, North-South Street, Eastern Sidewalk

The overall PET trend, demonstrates how insignificant a grid rotation is, to the thermal comfort (Table 17).

Table 17: Average PET values for North-South streets rotation

Receptors	Grid Rotation= 0°	Grid Rotation= 30°
Middle	34.20	35.15
West	35.34	34.87
East	34.46	34.55

Altogether, a 30° rotation of the street canyons provides better thermal comforts at the pedestrian level in the east-west oriented streets, while any rotation does not have a significant effect in north-south canyons.

Reflectivity

The simulation results demonstrate a direct relationship between the reflectivity of surface materials and the PET values. This trend is visible in all the receptors and its effect of the average daytime PET value seems to be the same on all the parts of a street profile (Table 18).

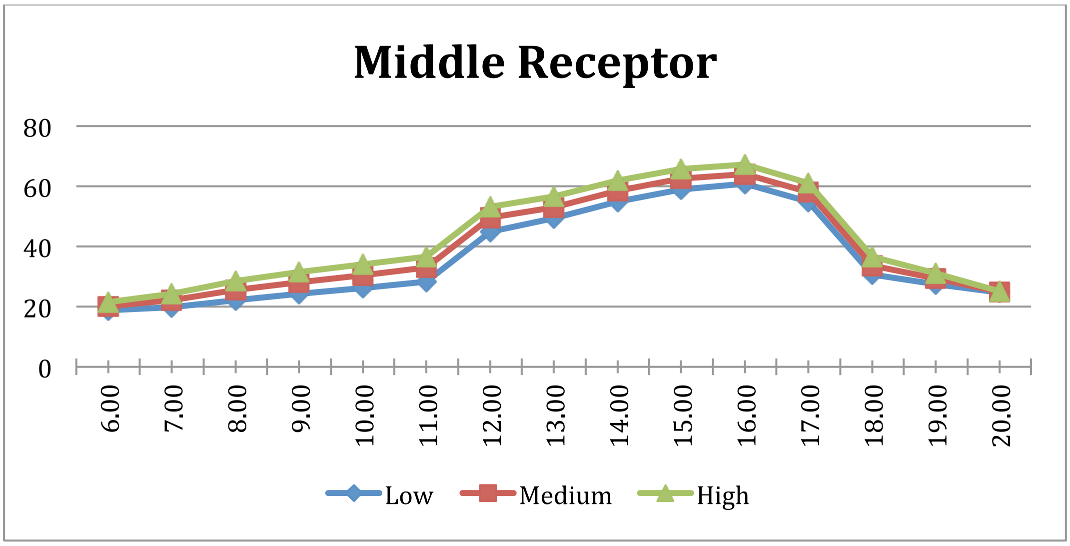

Figure 80: PET values during the day for various material reflectivity values, Middle Receptor

In all the receptors, the alternative with highest reflectivity seems to have around 9° higher PET than the one with lowest albedo. This difference is at its maximum during the peak solar radiation hours and seems to drop fast as the sun sets (Figure 81 and Figure 82).

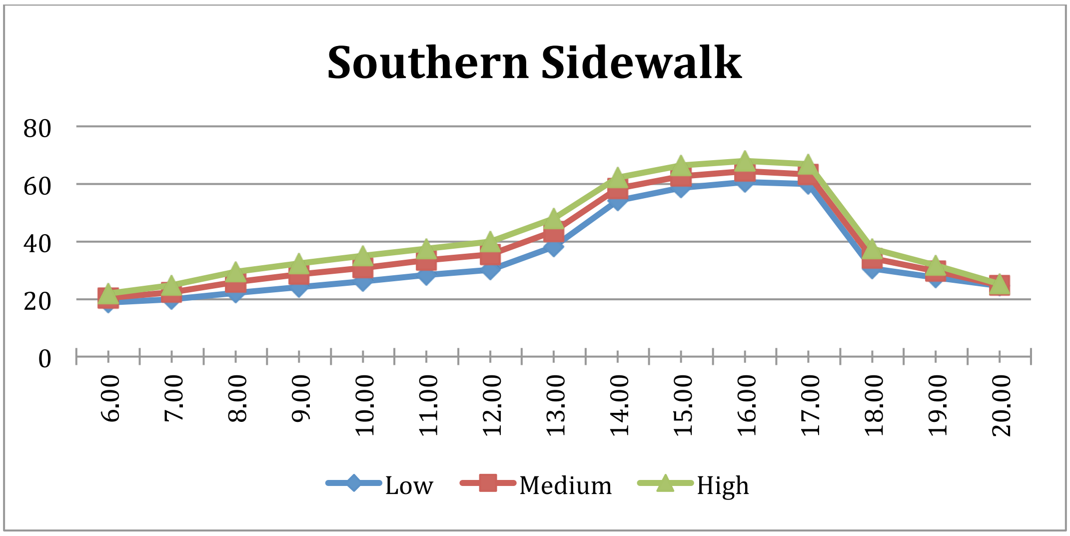

Figure 81: PET values during the day for various material reflectivity values, Southern Sidewalk

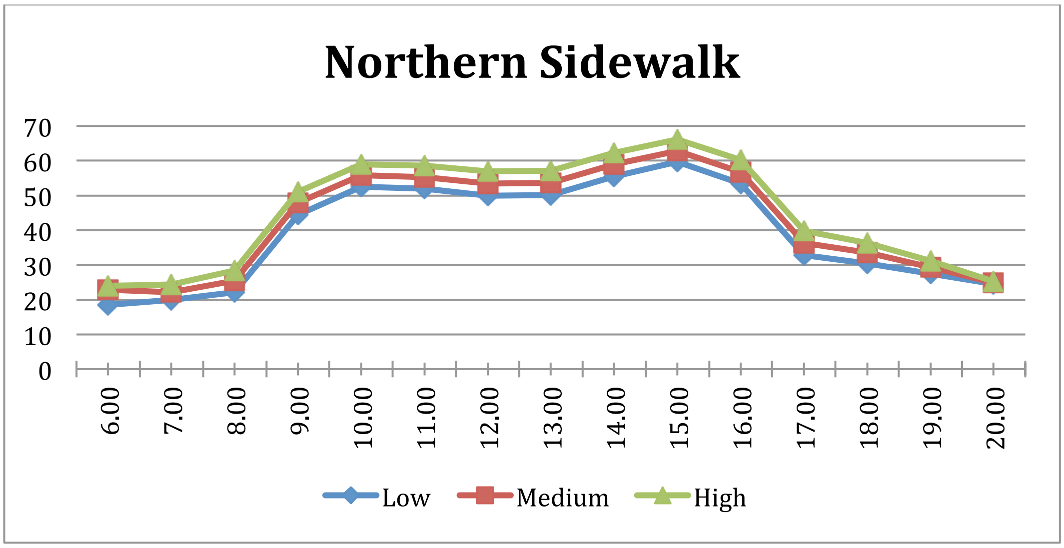

Figure 82: PET values during the day for various material reflectivity values, Northern Sidewalk

As mentioned before, an important factor in the calculation of PET is the Mean Radiant Temperature. Increased reflectivity of materials increases the radiation, which is reflected back into the environment by building surfaces. This leads to a lower thermal comfort, especially in canyons with lower H/W ratio, where the surfaces are exposed to more solar radiation for longer periods. Therefore, materials with lower reflectivity are more desirable in this environment.

However, higher reflectivity of a surface results in less energy absorption and ergo lower surface temperature. This lower surface temperature does affect the PET, but it is overshadowed by higher radiation available in the environment.

Table 18: Average PET values for different levels of reflectivity

Receptors	Low	Medium (Base)	High
Middle	36.41	39.53	42.33
South	34.92	38.55	41.78
North	39.57	43.29	46.02

Conductivity

Concerning building materials, another factor that was analyzed, was the thermal conductivity. The simulations proved that, although conductivity plays an important role on indoor energy efficiency, it has no effect on the outdoor thermal comfort. However, heat capacity of materials may be influential on outdoor thermal comfort, but it was not possible to perform simulations with various heat capacity alternatives.

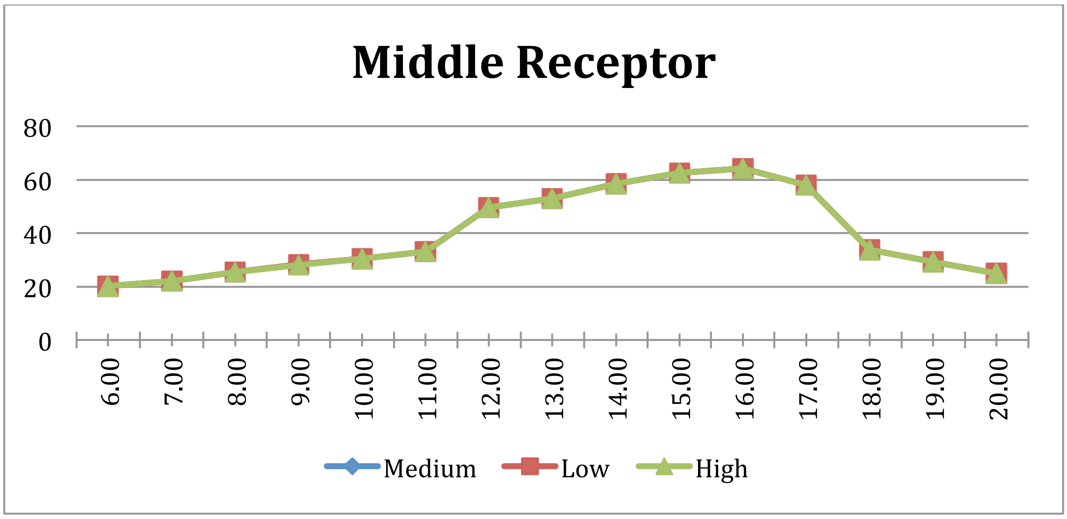

Figure 83: PET values during the day for various material conductivity values, Middle Receptor

For all the receptors, the results were almost identical (

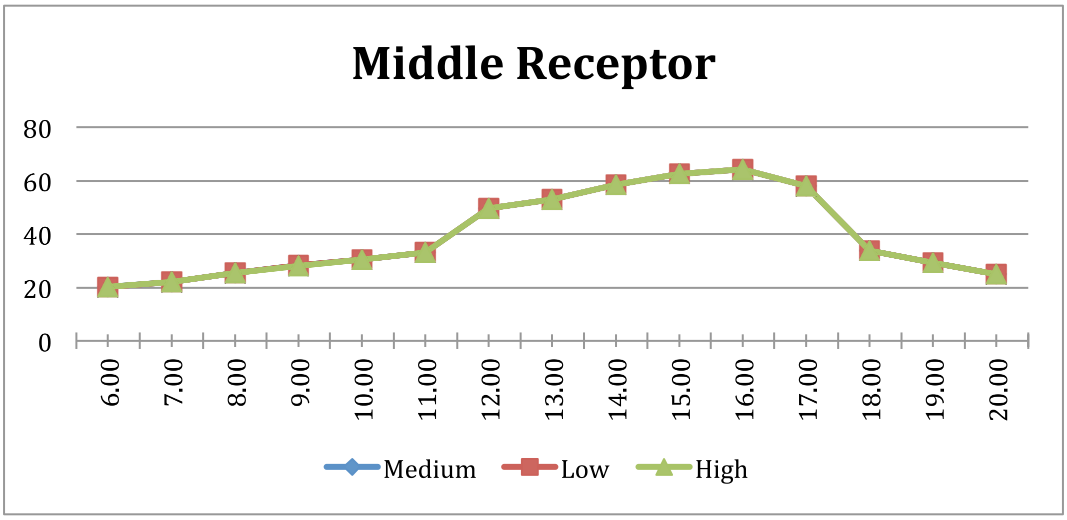

Figure 83, Figure 84 and Figure 85).

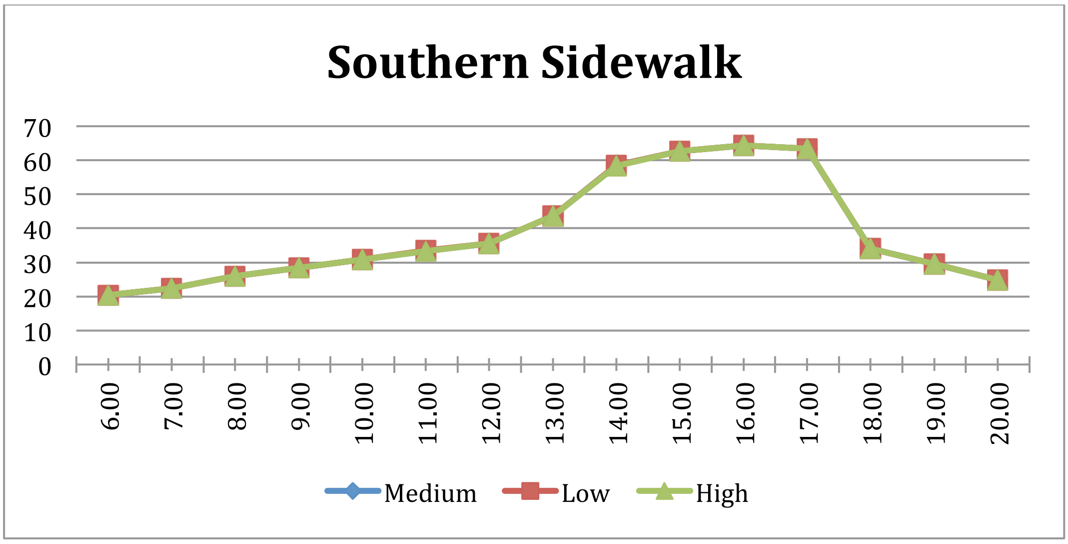

Figure 84: PET values during the day for various material reflectivity values, Southern Sidewalk

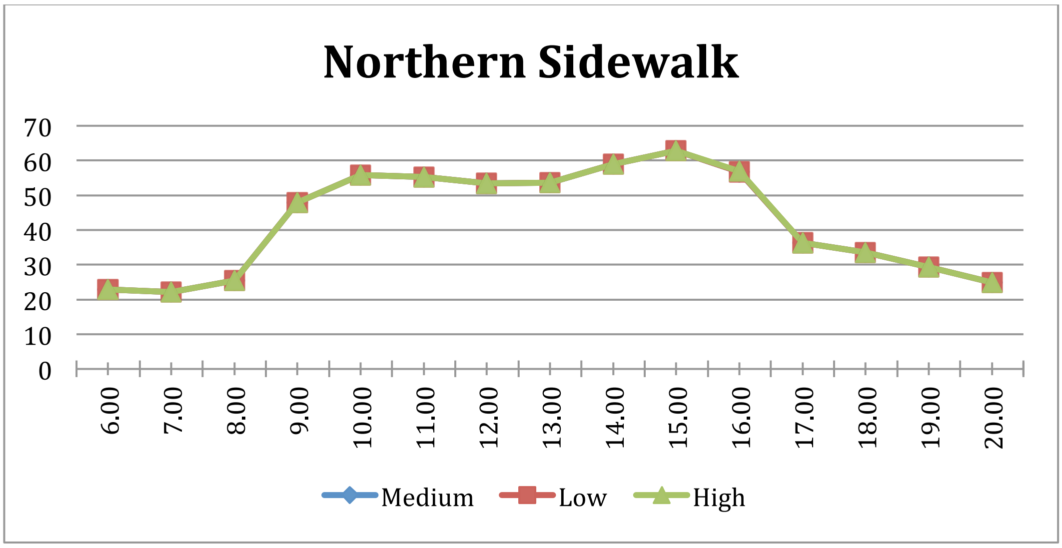

Figure 85: PET values during the day for various material reflectivity values, Northern Sidewalk

The discrepancy in average daytime PET values is under 0.02°C, which is in an acceptable range of model accuracy and well negligible. Therefore, heat conductivity of building materials plays no role at all on the thermal comfort situation of outdoor spaces.

Table 19: Average PET values for different levels of conductivity

Receptors	Low (Base)	Medium	High
Middle	39.53	39.53	39.52
South	38.55	38.54	38.53
North	43.29	43.28	43.29

Plot coverage

This stage of the investigation proved that the location of a building within its plot, in relation to the street in focus, is effective on the outdoor thermal comfort. This statement is only valid for east-west street canyons, since in north-south oriented streets, the buildings already line up both sides of the pathway, while in east-west streets, the northern boundary of the street is just a dividing wall and not a building mass.

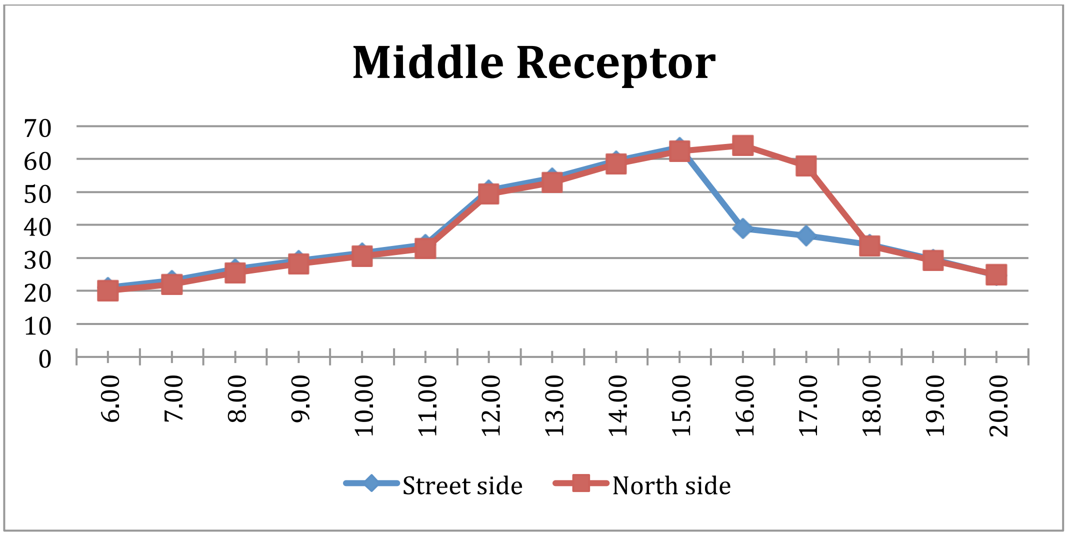

Figure 86: PET Values for various plot coverage styles, Middle Receptor

In all the receptors, the footprint of the building mass does not have an effect on thermal comfort before the afternoon hours. In northern sidewalks, this difference starts at around 14:00 h, while in other receptors the trend is identical until later hours.

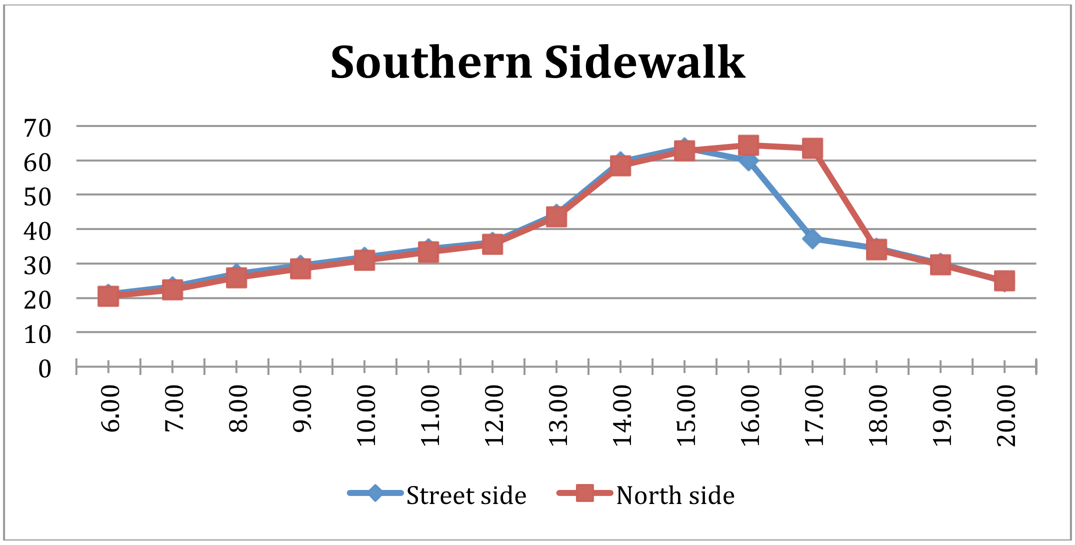

Figure 87: PET Values for various plot coverage styles, Southern Sidewalk

In streets where buildings are configured to occupy the street side of the plot (instead of 60% of the northern plot area), PET drops earlier.

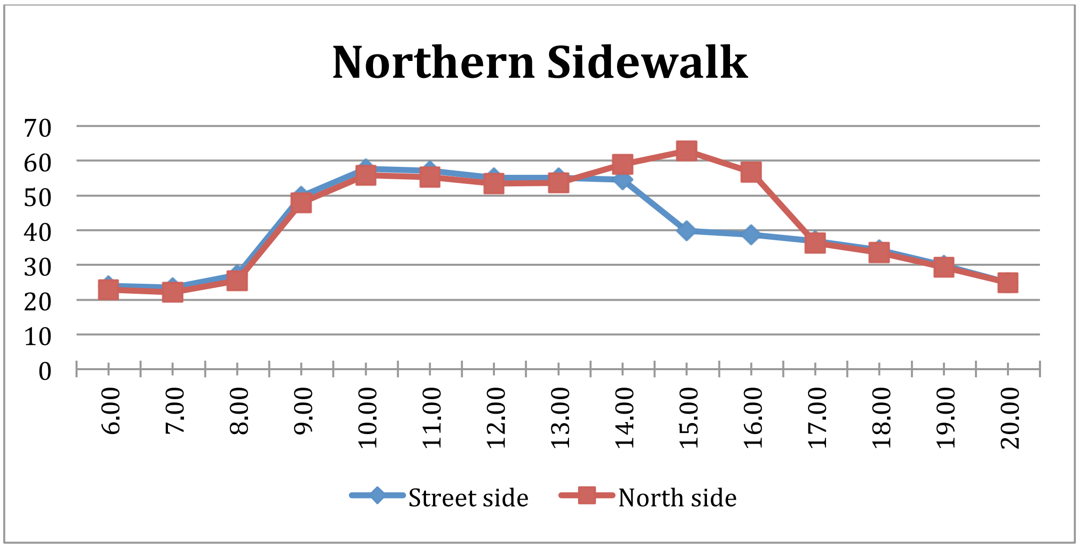

Figure 88: PET Values for various plot coverage styles, Northern Sidewalk

However, as this alternative is only effective on limited hours during the day, the difference in the average daytime PET value is around 2° which is not very significant (Table 20).

Table 20: Average PET values for alternatives in plot coverage

Receptors	North side (Base)	Street side
Middle	39.53	37.21
South	38.55	37.11
North	43.29	40.55

Balconies

In this research, balconies were studied as a main shadow-providing element of urban form. Although this urban feature does not have a significant effect on the thermal comfort of the middle receptor (Figure 89), it provides a much more comfortable thermal situation in the sidewalks.

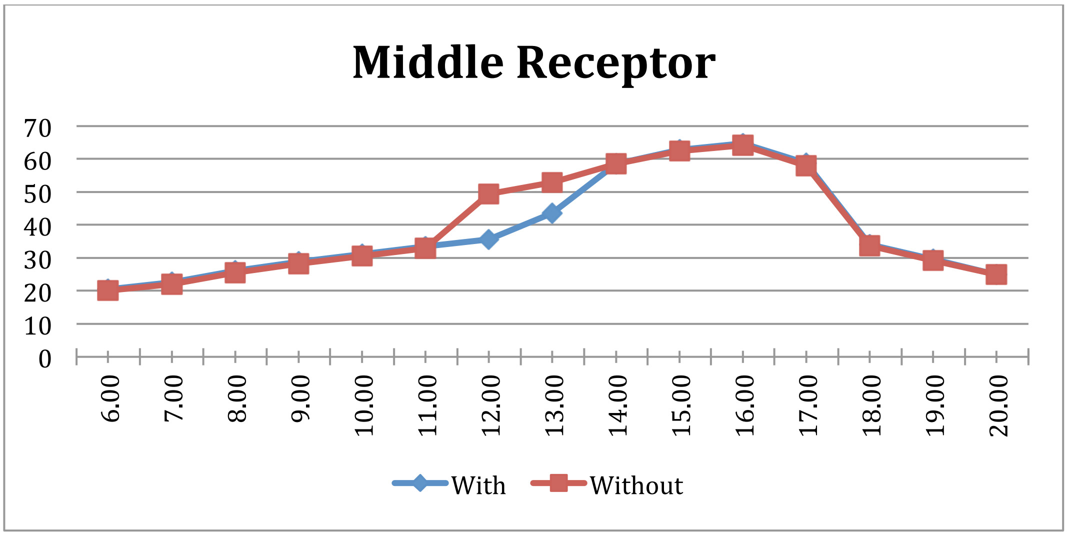

Figure 89: PET values throughout the day, with and without Balconies, Middle Receptor

Considering the southern sidewalk, balconies do not offer a tangible change in PET value until 13:00 h, as there is already shadow cast on this sidewalk by the buildings. PET is at a steady level until 16:00 h (around 40° that is not much higher than the upper comfort limit), and afterward, as direct sunlight penetrates even under the balconies, PET rises to the same level as the alternative without any balconies (Figure 90). After 17:00 h, both alternatives have a similar PET decrease rate.

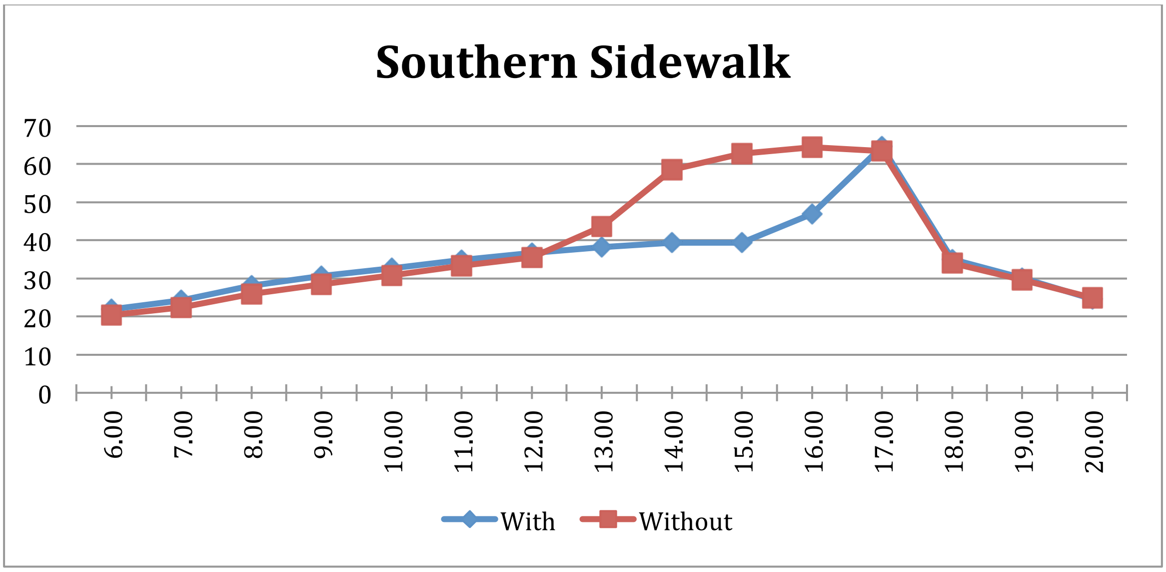

Figure 90: PET values throughout the day, with and without Balconies, Southern Sidewalk

In northern sidewalks, balconies are effective in morning hours. The main difference made by balconies in this side of the street is between 8:00 h and 10:00 h, when the balconies block direct sun light. However, after this time, solar radiation penetrates under the balconies and PET rises to the same value as the other alternative (Figure 91).

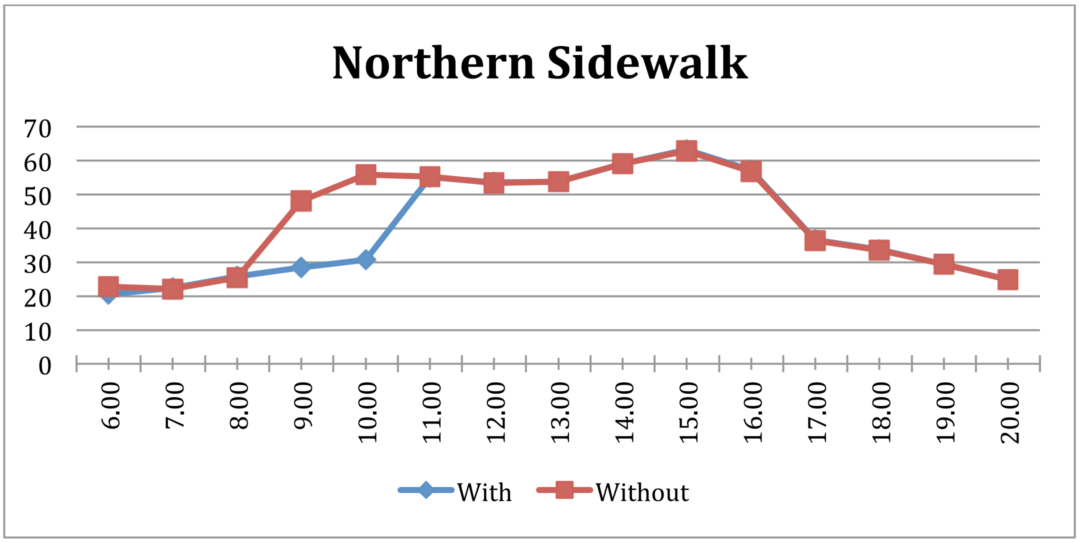

Figure 91: PET values throughout the day, with and without Balconies, Northern Sidewalk

As predicted, balconies do not effect the average daytime PET value in the middle of the street, but they do reduce this average value about 4° in the sidewalks (Table 21).

Table 21: Average PET values for alternatives in balconies

Receptors	With balconies	Without balconies (B)
Middle	38.36	39.53
South	35.19	38.55
North	39.61	43.29

Vegetation

The situation with urban vegetation and their effect on outdoor thermal comfort is very complicated. Apart from the transpiration effect, which cools down the temperature, the main effect of urban trees seems to be their shadow.

For the middle receptor, in the alternative with trees, the PET value peaks two times, when the middle of the street is not covered by tree shadows. Other than those two peak points, the alternative with trees has a 15° lower PET than the base case (Figure 92).

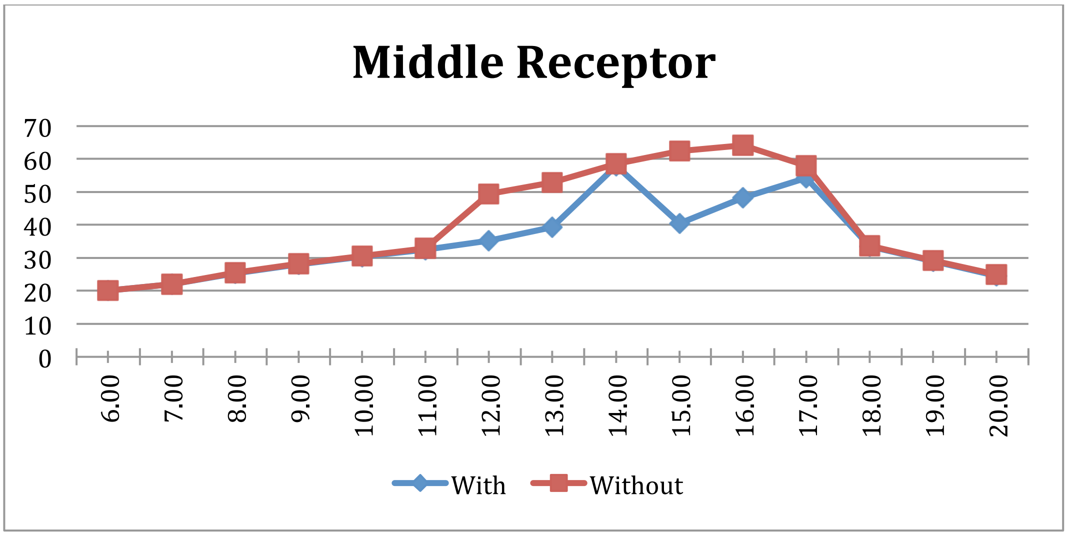

Figure 92: PET values throughout the day, with and without Vegetation, Middle Receptor

Similar to the middle receptor, the southern sidewalks enjoys a much lower PET value, except for two peak times, when there is direct sunlight under the trees (Figure 93). In this case, the difference in PET between two cases is as large as 25°.

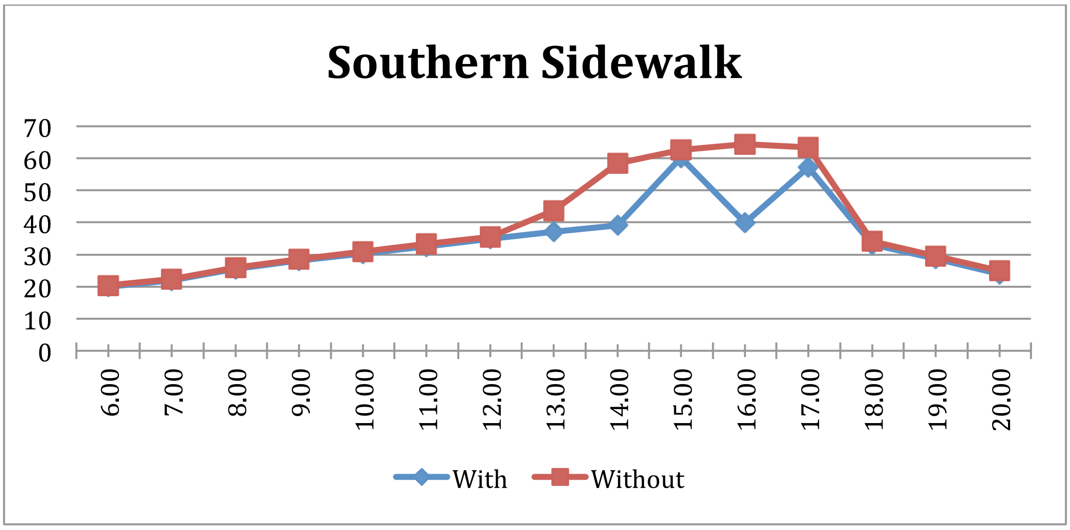

Figure 93: PET values throughout the day, with and without Vegetation, Southern Sidewalk

The effects of trees seem to be very significant on the thermal comfort at the northern sidewalk. These trees provide shadow for the most of the day. The PET value seems to follow the same trend as the alternative without trees, and the maximums are the same, but it is generally lower around 15° (Figure 94). However, after 15:00 h, trees seem to have to tangible effect on the thermal situation. The lower PET value under tree crowns has two reasons. Firstly, less solar radiation reaches those areas. Secondly, the heat absorbed by the ground surface is strongly reduced under the vegetation (up to 200 Wm^{-2} according to (Ali-Toudert and Mayer 2007a)). Therefore, the heat emitted upwards and absorbed by the human body is reduced likewise.

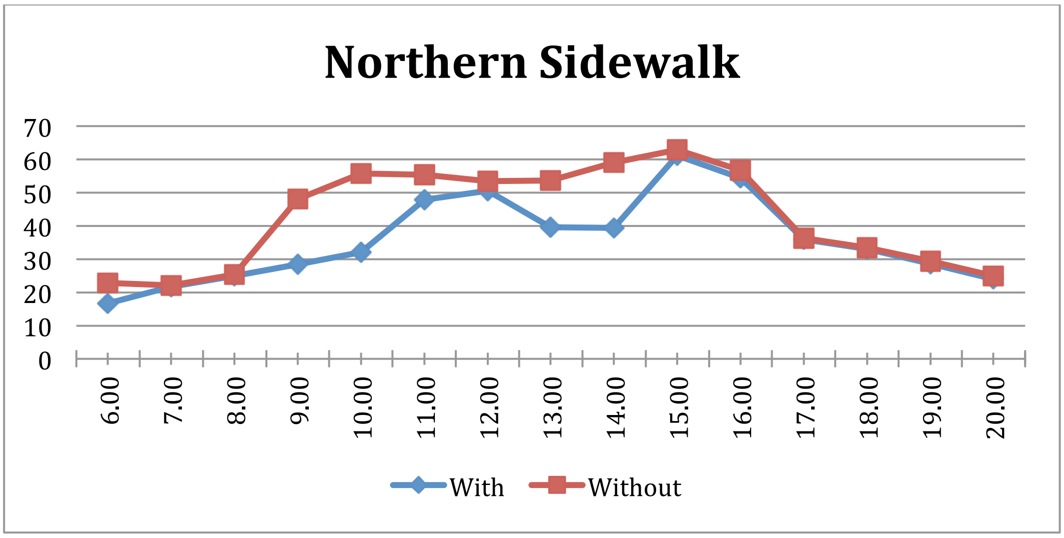

Figure 94: PET values throughout the day, with and without Vegetation, Northern Sidewalk

The differences in the average daytime PET values are indeed substantial (Table 22). This table shows the importance of rather tall urban trees on the thermal comfort of both sidewalks, especially the northern one, where the difference in average is almost 8°.

Table 22: Average PET values for alternatives concerning vegetation

Receptors	With Vegetation	Without Vegetation (B)
Middle	34.72	39.53
South	34.18	38.55
North	35.88	43.29

8.3. Optimization

The parametric study proved that the H/W ratio and provision of horizontal shading had the greatest influence on thermal comfort at street level. Moreover it showed that the properties of building materials could play a major role in the thermal situation of the street. To study the effects of these alternatives in urban configurations all together and achieve an optimized street design, a best-case scenario was devised. In this model, every parameter was assumed at its best value, based on the results of the previous simulations.

The parameters used in the best-case models were as follows:

Table 23: Model properties for optimized alternative simulations

Direction	East-West	North-South
H/W ratio	2	2
Orientation	30° rotated	30° rotated
Reflectivity	Low = 0.1	Low = 0.1
Conductivity	Low = 0.7 W/m°C	Low = 0.7 W/m°C
Plot coverage	60% street side	-
Balconies	2 meters extension, both sides	2 meters extension, both sides
Vegetation	Rows of trees, both sides	Rows of trees, both sides

The results of these enhanced simulations are quite fascinating. Figure 95 demonstrates how improved urban configurations affect the general thermal comfort throughout the day, in comparison to the base settings. With the enhanced configuration, the PET exceeds the upper comfort limit only around 14:00 h, when the solar radiation is almost perpendicular to the earth.

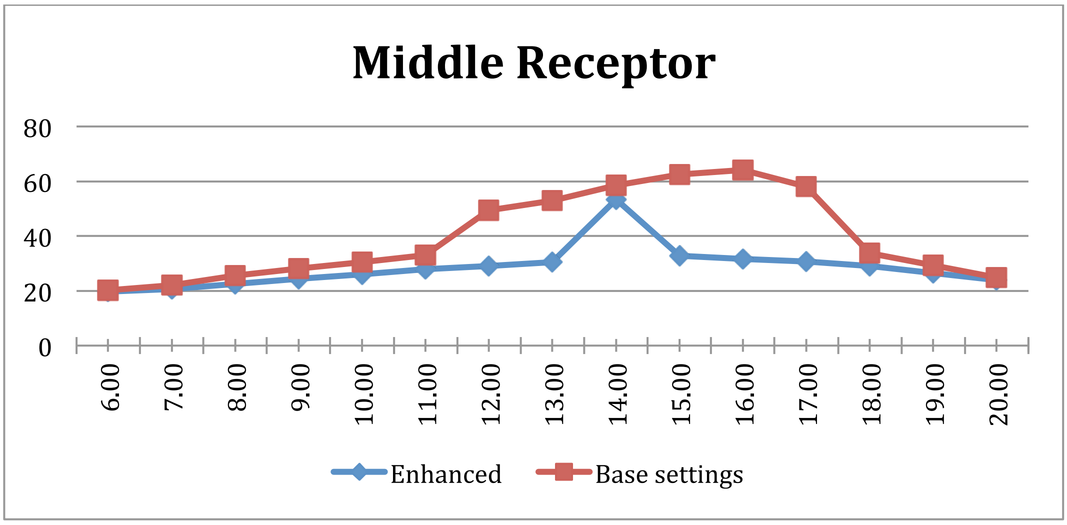

Figure 95: PET values, basic and enhanced urban configurations, East-West canyon, Middle Receptor

In Southern and Northern sidewalks (Figure 96 and Figure 97 respectively) even during the peak radiation times, PET remains well below the upper thermal comfort limit (33°C).

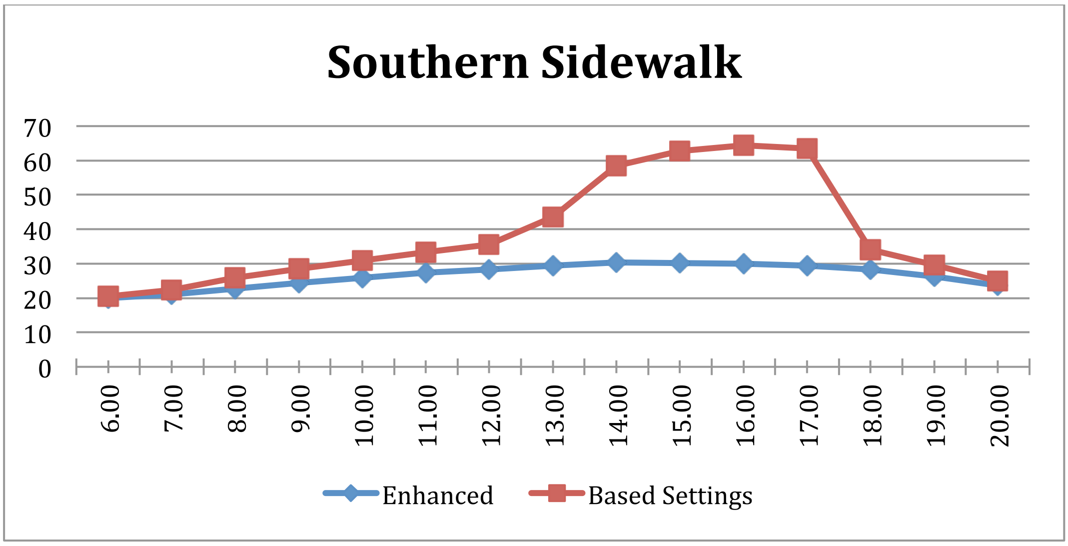

Figure 96: PET values, Basic and enhanced urban configurations, East-West canyon, Southern sidewalk

The surface of these sidewalks is well covered by shadows during daytime hours; therefore T_{mrt} does not increase radically as it does in the base case. This controlled T_{mrt} will keep the PET at a rather steady value, within the human comfort range.

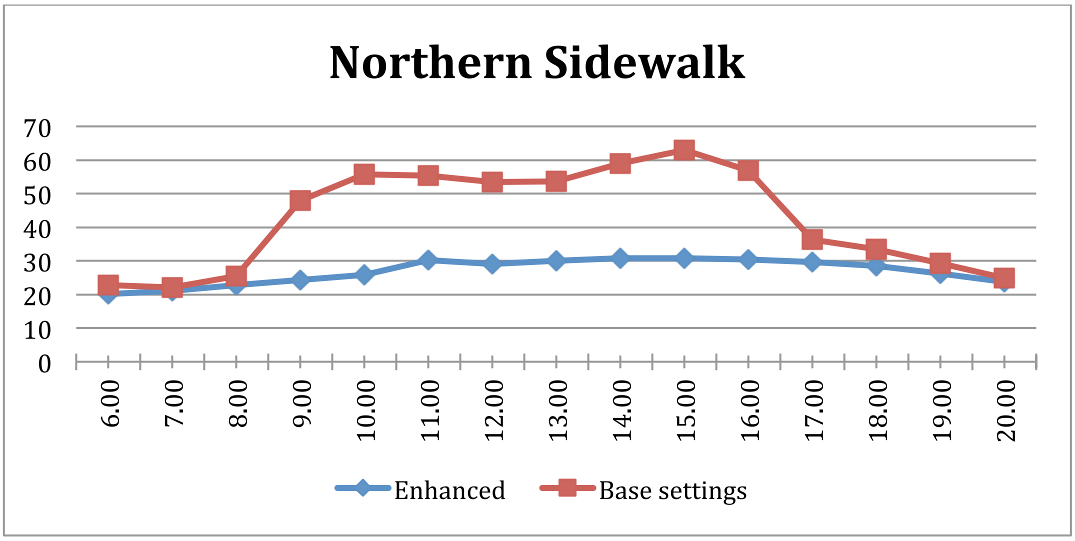

Figure 97: PET values, Basic and enhanced urban configurations, East-West canyon, Northern sidewalk

The average daytime PET proves that these changes in the urban structure can reduce the overall PET, between 11° to 16°.

Table 24: Average daytime PET values for Basic and Optimized settings in East-West canyons

Receptors	Base settings	Enhanced settings
Middle	39.53	28.57
South	38.55	26.48
North	42.62	26.91

In North-South oriented streets, the optimized configuration performs similar to the East-West oriented canyons. The addition of these urban features leads to a generally lower PET during the day, never exceeding the upper thermal comfort limit, even during peak radiation times (Figure 98).

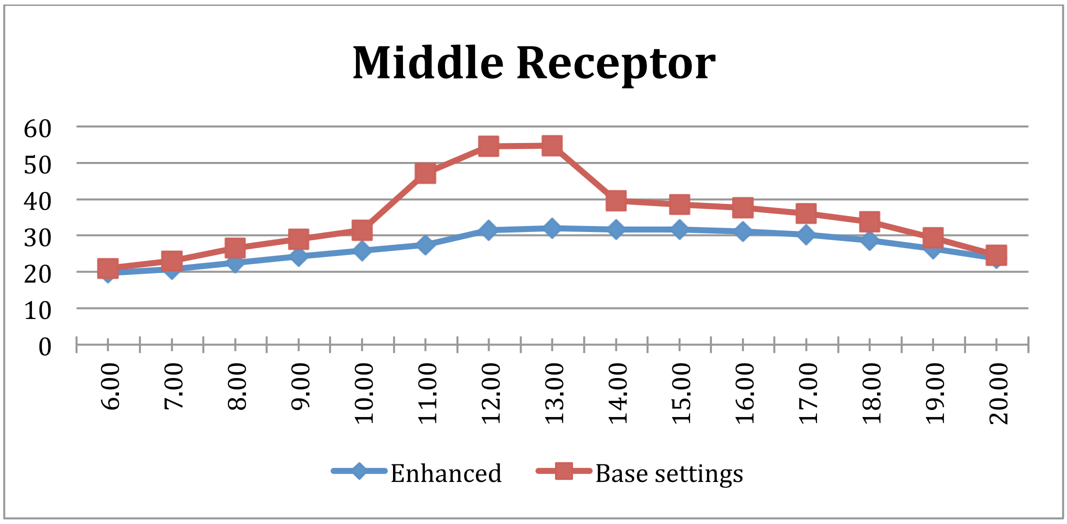

Figure 98: PET values, Basic and Enhanced urban settings, North-South canyon, Middle Receptor

The Western and Eastern sidewalks exhibit the same pattern (Figure 99 and Figure 100). In the western sidewalk, with the basic configuration, the PET reaches 56°, while in the same point with the enhanced features, PET never rises beyond 30°.

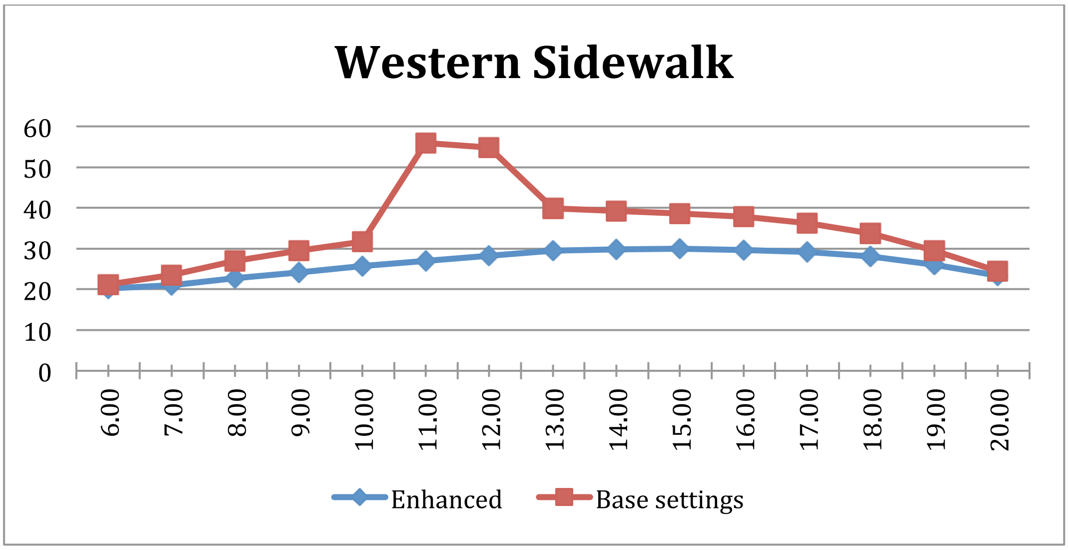

Figure 99: PET values, Basic and enhanced urban settings, North-South canyon, Western sidewalk

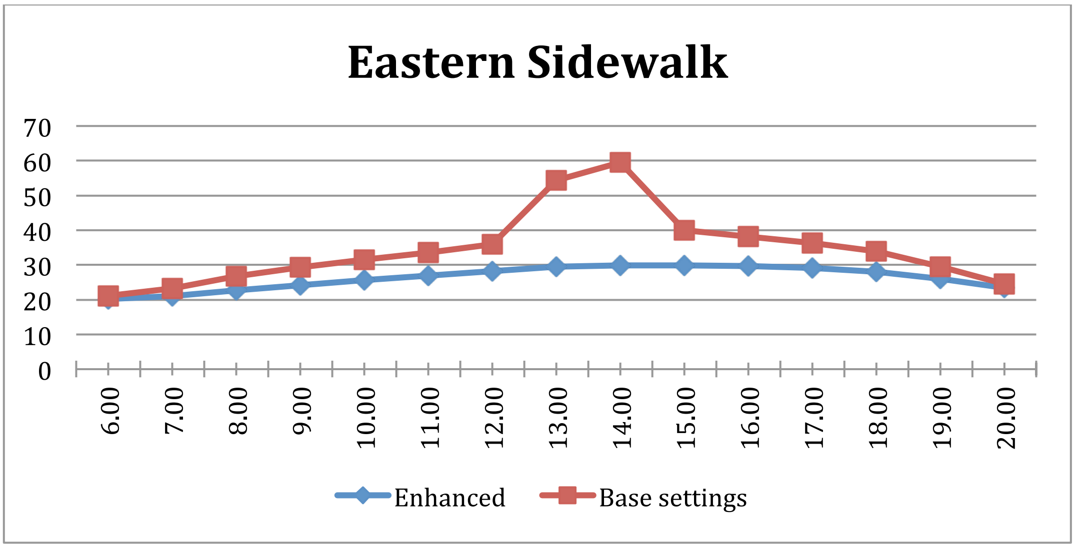

Figure 100: PET values, Basic and enhanced urban settings, North-South canyon, Eastern sidewalk

The difference in the average daytime PET between base case and optimized settings is around 8° (Table 25). Although this difference is less than its counterpart in the East-West canyons, it is still considerable.

Table 25: Average daytime PET values for Basic and Optimized settings in North-South canyons

Receptors	Base settings	Enhanced settings
Middle	35.15	27.15
West	34.87	26.31
East	34.55	26.32

Chapter 9: Analysis and Results IV

9. Energy Calculations

9.1. Potential

9.1.1. Solar Energy

Solar radiation is an important source of renewable energy. The horizontal solar irradiation varies globally and is at its peak point in the solar belt.

With about 300 clear sunny days a year and an average of 2,200 kilowatt-hour solar radiation per square meter, Iran has a great potential to tap solar energy (Zawya 2010). In comparison to the Ruhr area with an average of 900kwh/$m^{2,}$ and far less days with clear sky, solar radiation is a never-ending source of renewable energy that deserves more attention and investment in the Iranian context.

In Kerman, the average annual sum of global horizontal irradiation is about 2,100 kwh/m^2 (Figure 102). In the Iranian context, the photovoltaic systems' efficiency never drops below 25% during the day, and on average these systems produce 80% of their maximum capacity (Iranian Fuel Conservation Company 2012).

In Kerman, due to very low precipitation, the building roofs are flat; therefore it is possible to align the solar collectors to the most efficient direction as the buildings architectural form does not dictate a specific direction.

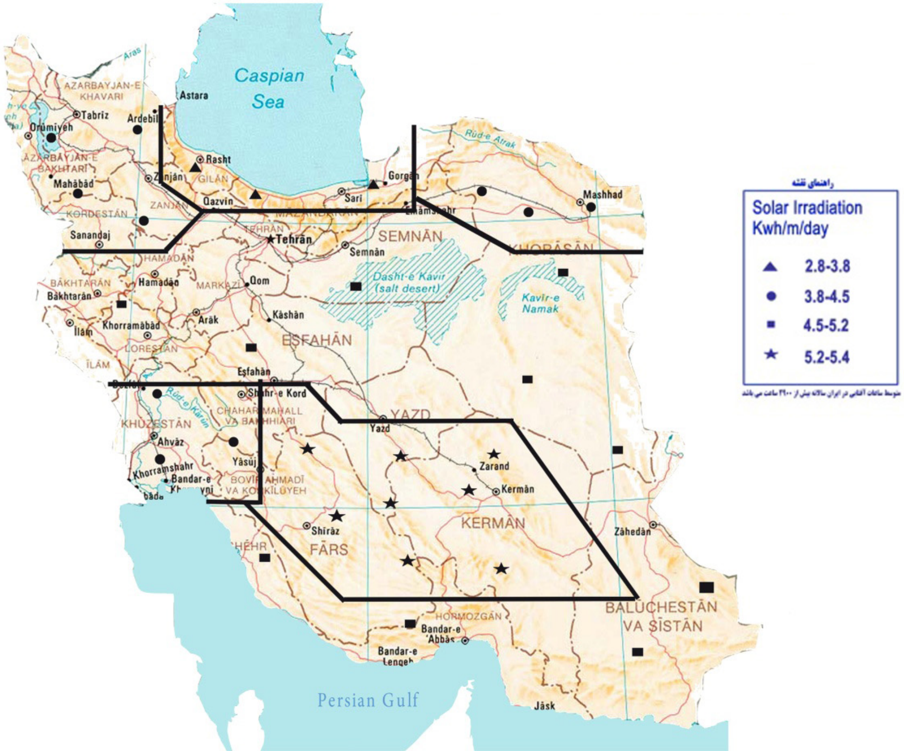

Figure 101: Average solar radiation per day in Iran (source: www.suna.org.ir)

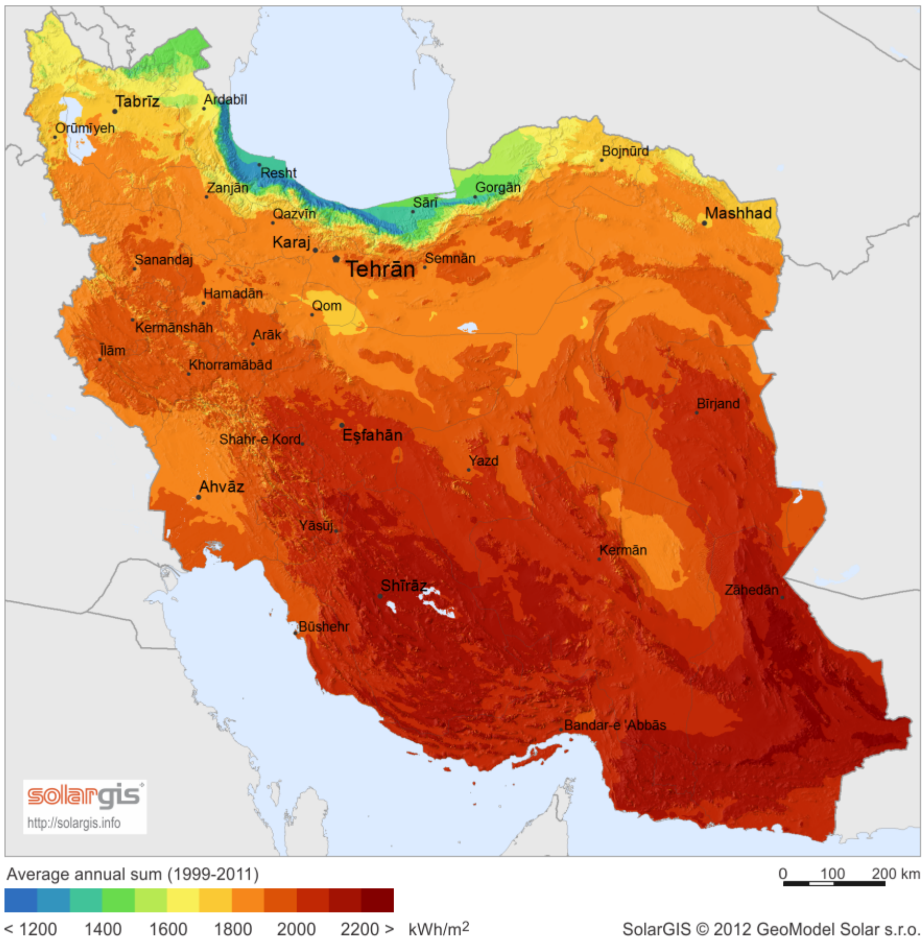

Figure 102: Average Annual Solar Irradiation

9.1.2. Wind

In 2009, the Renewable Energy Organization of Iran (SUNA) ordered a feasibility study on the potentials of wind farms across the nation. Lahmeyer International GmbH, a German firm, performed this analysis. They calculated the spatial distribution of the annual mean wind speed within the whole country. The calculations were based on the numerical flow simulations with the three-dimensional atmospheric model KLIMM, originally developed at the Institute of Atmospheric Physics of the University of Mainz, Germany. By use of mesoscale atmospheric simulations, the three-dimensional atmospheric flow within the topographic terrain is calculated for various distinctive meteorological situations (individual scenarios). Apart from the meteorological situation, the calculation procedure takes into account the complex structure of the terrain, i.e. topographic elevation and land-use distribution. All results of the individual scenarios were combined to the long-term representative annual mean wind speed. This was done based on long-term upper air wind measurement data and data from long-term wind measurements near ground. These data are providing statistical frequency share for each of the individual scenarios. For final calibration, SUNA and LI implemented a short-term measurement campaign, in order to improve the accuracy of the calculation, after which a refined wind map was calculated (Renewable Energy Organization of Iran 2010).

The aim of this wind map is to facilitate the identification of sites, which can generally be considered as potential wind farm sites due to their wind potential. Especially the wind map can serve as a helpful decision tool for wind farm developers as well as for communities who would like to specify their most suitable areas in respect of wind energy potential. However, the annual mean wind speeds cannot be solely taken as input for a precise energy production calculation as required for financial and economic analyses in the course of detailed wind farm planning procedures. This map rather shall serve for decision support in the selection of suitable wind farm area with comparative good wind conditions within investigated region. According to this investigation, the whole country has the potential of producing about 18,000 MW electricity in the wind farms, of which only 109.4 Megawatts has been harnessed (Renewable Energy Organization of Iran 2012).

In case of Kerman, the annual mean wind speed is less than 5 m/s within the city limits, which is not very ideal for commercial production of electricity. However, this wind speed is enough to operate windpumps, which were also used in the city during 1930s to 1980s. Some of these windpumps still remain in the old farmlands within the city (East of Kerman) that have not been converted to residential areas yet. These windpumps are a part of the local skyline heritage, but since private stakeholders own them, there is no specific plan for their preservation and renovation.

9.2. Cost-benefit analysis

As mentioned before, there is a very large potential for harnessing renewable energy sources in Kerman, especially from the solar radiation. However, currently less than 2% of the total national energy production is from renewable sources, most of which is hydro-electrical. As of 2010, Iran had 8,500MW of hydroelectric capacity and 130MW of wind energy capacity (Renewable Energy Organization of Iran 2012).

Production of renewable energy is a main theme in the mitigation strategies recommended by the German officials. In order to investigate the feasibility of these strategies in the Iranian context, cost-benefit analyses were performed on two sample projects. The first one is the solar electricity production through photovoltaic modules, and the second one is the solar thermal energy, namely solar water heating.

9.2.1. Solar electricity

Electricity prices in Kerman, as of 2013, range between 270 – 1900 Rials/kWh (Organization for Protection of Consumers and Producers rights 2013).

In summer 2003, the Ministry of Power published a guideline on the conditions and prices of electricity purchase by the government. This document, which was slightly updated in 2006, was devised to address the introduction of private power plants (on an industrial scale), and so far is the only official document governing the production of electrical energy by the private sector. According to this document, the government buys the produced energy with a price ranging between 50 – 448 Rials/kWh, depending on the time and date of production and demand (Ministry of Power 2003). Between March 2013 and September 2013, the median purchase price was 316.18 Rials per kWh (Iran Grid Management Co. 2013). The gap between the sell and buy prices of the energy is very notable. There are talks to increase the feed-in-tariff to 13 cents/kWh, roughly around 3225 Rials/kWh but it is not finalized yet (Alic 2012).

Although private investors may be interested in investing on the Iranian electrical energy market on an industrial scale, but there is not enough economical incentives for the general public to invest on small-scale energy production units. Moreover, the source of this electrical energy does not play a role on the price of the final product and the production of renewable energies is not encouraged through the pricing regime.

In 1391 (2011-2012), the total electrical energy consumption of Kerman was 417,631,601 kWh. With the population of 534,441 (The Statistical Center of Iran 2011), the per capita energy consumption is 781.43 kWh per year.

RETScreen calculates a number of key indicators of financial viability. Three of the best known are the Simple Payback, the Net Present Value (NPV), and the Internal Rate of Return (IRR). The simple payback is the number of years required for the initial cost of the project to be paid for out of annual savings. While it is often used, the simple payback is misleading and ignores financing and long-term cash flows, such that project benefits beyond the payback period are accorded no value (RETScreen International 2011). If only the simple payback period is considered, very profitable projects may be missed. However, when cash flow is tight, a quick payback may be essential.

The NPV is the golden measure of discounted cash flow mechanics. It is the sum of all costs and benefits, adjusted according to when they occur in the project. If the NPV is positive, then the project is financially attractive at the discount rate specified by the user. If it is negative, then money would be more profitably invested elsewhere. Unfortunately, picking an appropriate value for the discount rate can be tricky.

The IRR, also known as the return on investment (ROI), is the true interest yield of the project over its lifetime and does not require the user to assume a discount rate. The IRR for a project can be compared to the return associated with investing the same amount of money in competing investments with a similar level of risk. An investor will typically have a "hurdle rate," or target IRR that they require an investment to exceed. The IRR generally yields the same results as the NPV, although it can give confusing values in certain cases, such as when cashflows are always positive.

The results of this feasibility study are quite astonishing. With the current power purchase prices the payback period would be more than the projected lifetime of the system. Therefore, under current circumstances, these projects will not be feasible at all.

Table 26: RETScreen results

Electricity Export Escalation Rate	Debt Interest	IRR	NPV Rials	Equity Payback Years
10%	4%	Negative	-2,298,438,100	13.8
10%	12%	Negative	-2,362,676,900	> Project
10%	24%	Negative	-2,468,362,700	> Project
15%	4%	Negative	285,349,500	10.0
15%	12%	Negative	221,110,700	11.0
15%	24%	Negative	115,424,900	12.4
20%	4%	24.1%	6,372,756,300	8.5
20%	12%	22.3%	6,308,517,400	9.2
20%	24%	20,00%	6,202,831,700	10.2

With the introduction of a rather attractive FiT, the project's equity payback period is between 8.5 and 13.8 years (Table 26). The Electricity Export Escalation Rate seems to play the most important role in these fluctuations. This rate should be reasonably adjusted, considering the national inflation rates. Furthermore, since the equipment prices are very high, the government has to create attractive financial incentives in order to endorse private investments in renewable energy sector. These incentives can be in form of low interest loans (which have been investigated in the RETScreen analysis), or long-term contract with the producers. The German model of Feed-in-Tariffs seems to be applicable in this context.

9.2.2. Solar water heating

On average every person consumes 50 liters of hot water each day. The average tap water temperature is 20°C and the desired hot water temperature is around 55°C. The specific heat capacity[33] of water is 4.18 kJ/kgK. Therefore, in order to provide a family of four with hot water:

4.18 kJ/kgK * 35° * 200 kg = 29,260 kJ energy is required.

The efficiency of the common water heaters used in this region is about 70% (heat loss due to storage is also included), thus the total energy required

[33] Specific heat capacity is the measurable physical quantity of heat energy required to increase the temperature of a gram of a material by one degree

per day would be 41,800 kJ. These water heaters consume natural gas. The gross heat of combustion of one cubic meter of commercial quality natural gas in this city is around 39 MJ. Ergo, a medium sized family consumes around 1.1 m^3 of natural gas for hot water each day.

Natural gas prices vary according to the region and the consumption of the users. As of summer 2013, these prices vary between 300 – 3500 Rials per cubic meter (Organization for Protection of Consumers and Producers rights 2013). For the purpose of this research, the median value of 1900 Rials/m^3 is assumed as the reference value. Therefore, a price that a family would pay for hot water per year would be:

1.1 m^3 * 1900 Rials/m^3 * 365 days = 762,850 Rials per year

As the solar water heater requires maintenance every two years[34], which costs around 500,000 Rials per year, the family will save 262,850 Rials per year, if they switch to the solar water heating.

Table 27: Costs-effectiveness of Solar Water Heating

Renewable Energy Production Unit	Thermosyphon solar water heater
Capacity	200 liters
Costs of appliances	21,000,000 Rials
Installation costs	2,000,000 Rials
Maintenance costs, every two years	1,000,000 Rials
Payback Period	More than 87 years

This means that considering the investments in appliances and costs of installation, the payback period[35] would be more than 87 years, which is far from being financially viable, as it is more than the lifetime of the mentioned solar equipment. However, this calculation does not account for the time value of money, risk, financing, or other important considerations, such as the opportunity cost.

However, Pouramiri and his colleagues (2011) demonstrate that by adopting solar water heating in a residential district with 151 units in Jiroft, Iran, 502.53 MWh of energy is conserved each year. This energy is equal to 304.53 metric tons of CO_2 emissions, which requires 105.7 acres of forestland to balance. This pollution is equal to 634.2 barrels of oil or 122763 liters of gasoline (Pouramiri, Samareh and Heydari 2011). Although these installations may not be

[34] Due to sediments in water

[35] Payback period refers to the period of time required to recoup the funds expended in an investment, or to reach the break-even point (Farris, Bendle, Pfeifer, & Reibstein, 2010).

economically attractive to the private homeowners with the current circumstances, but they can play a major role in the mitigation of climate change, as they reduce GHG emissions.

Figure 103: Solar Water Heaters in Jiroft (Source: mehr-abad.ir)

9.3. Feed-in-Tariff in Germany

Feed-in electricity tariffs have been introduced in Germany to encourage the use of new energy technologies such as wind power, biomass, hydropower, geothermal power and solar photovoltaics. Feed-in tariffs are a policy mechanism designed to accelerate investment in renewable energy technologies. The mechanism provides long-term contracts to renewable energy producers, typically based on the cost of generation of each technology (Couture, et al. 2010). Technologies such as wind power, for instance, are awarded a lower per-kWh price, while technologies such as solar PV and tidal power are offered a higher price, reflecting higher costs.

In 1990, Germany adopted its "Stromeinspeisungsgesetz" (StrEG), or "Law on Feeding Electricity into the Grid". The StrEG required utilities to purchase electricity generated from renewable energy suppliers at a percentage of the prevailing retail price of electricity. The percentage offered to solar and wind power was set at 90% of the residential electricity price, while other technologies such as hydropower and biomass sources were offered percentages ranging from 65–80%. A project cap of 5 MW was included (Gipe 2009).

While, in the beginning, Germany's StrEG was insufficient to encourage costlier technologies such as photovoltaics, it proved relatively effective at encouraging lower-cost technologies such as wind, leading to the deployment of 4,400 MW of new wind capacity between 1991 and 1999, representing approximately one third of the global capacity at the time (BMU 2000). An additional challenge that StrEG addressed was the right to interconnect to the grid. The StrEG guaranteed renewable electricity producers grid access (BMU 2000).

Germany's Feed-in Law underwent a major restructuring in 2000, re-framed as the Act on Granting Priority to Renewable Energy Sources ("Erneuerbare Energien Gesetz", German Renewable Energy Act). In its new form, it proved to be the world's most effective policy framework at accelerating the renewable deployment (Jacobsson and Lauber 2006).

Jacobsson and Lauber (2006) summarize the important changes as:

- Purchase prices were based on generation cost. This led to different prices for wind power, solar power, biomass/biogas and geothermal and for projects of different sizes.
- Purchase guarantees were extended to 20 years.
- Utilities were allowed to participate.
- Rates were designed to decline annually based on expected cost reductions, known as "tariff degression"

Since it was the most successful, the German policy (amended in 2004 and 2008) often was the benchmark against which other feed-in tariff policies were considered and other countries followed the German approach.

Long-term contracts are typically offered in a non-discriminatory manner to all renewable energy producers. Because purchase prices are based on costs, efficiently operated projects yield a reasonable rate of return (Lipp 2007).

Tariff rates for PV electricity vary depending on system size and location. In 2009, tariffs were raised for electricity immediately consumed rather than supplied to the grid with increasing returns if more than 30% of overall production is consumed on-site. This is to incentivize demand-side management and help develop solutions to the intermittency of solar power (Lang and Mutschler 2010). Tariff duration is usually 20 calendar years plus the year of installation. Systems receive the tariff in effect at the time of installation for the entire period.

The success of photovoltaics and their relative boom in Germany resulted in a drop in electricity prices of up to 40% during peak output times (Parkinson, Why power generators are terrified of solar 2012), with savings between €520 million and 840 million for consumers (Parkinson, Euro utilities declare war on solar PV 2012). Savings for consumers have meant conversely reductions in the profit margin of big electric power companies, who reacted by lobbying the German government, which reduced subsidies in 2012. Energy utilities lobbied for the abolition, or against the introduction, of feed-in tariffs in other parts of the world, including Australia and California. Increase in the solar energy share in Germany also had the effect of closing gas- and coal-fired generation plants (Parkinson, Five things we learned this week 2012).

Table 28: German Feed-in Tariffs in 2013 (Source: www.germanenergyblog.de)

Energy Source	Hydro-power	Land-fill gas	Sewage gas	Mine gas	Biomass	Geo-thermal	Onshore wind	Off-shore wind
Energy Capacity	< 500 kW	< 500 kW	< 500 kW	< 1 MW	< 150 kW	-	< 50 kW	-
FiT ct/kWh	12.57	8.47	6.69	6.74	14.01	25.00	8.80	15.00

As of 2013, the FiT ranges between 6.74 and 25.00 ct/kWh, depending on the sources of the produced energy (Table 28). The most detailed tariff scheme is developed for the photovoltaic systems (Table 29), with rates gradually declining over the months.

Table 29: German Feed-in Tariffs for Photovoltaic energy in 2013 (Source: germanenergyblog.de)

Month	Degression	Roof mounted < 10 kW_P	Ground mounted <10 kW_P
January	2.5%	17.02	11.78
February	2.2%	16.64	11.52
March	2.2%	16.28	11.27
April	2.2%	15.92	11.02
May	1.8%	15.63	10.82
June	1.8%	15.35	10.63
July	1.8%	15.07	10.44
August	1.8%	14.80	10.25
September	1.8%	14.54	10.06
October	1.8%	14.27	9.88
November	1.4%	14.07	9.74
December	1.4%	13.88	9.61

Chapter 10: Discussion and Conclusion

This chapter reviews the results of the analyses performed in this research and seeks to address research questions. It aims to provide proper alternatives for the development of Iranian midsized cities in the hot and arid climate, through suggestions to be implemented in urban design guidelines.

First, based on the results of studies performed in this research, the influence of urban design features on human outdoor thermal comfort is discussed. Later on, implications of these influences in urban design codes are discussed and developed. Afterwards, the climate policies in Iran are investigated and then the Iranian urban design paradigm is explored to identify climate considerations.

Subsequently, the energy situation in Kerman is discussed. Barriers to climate change and adaptive capacity are also examined. In the end, some suggestions for further studies are presented.

10.1. Effects of urban design on human thermal comfort

The PET values obtained in this research might be overestimated compared to real situations for many reasons, especially the wind direction. In this study, the direction of the wind was assumed perpendicular to the street canyon, which is the worst-case scenario. If the wind is blowing at an oblique or parallel direction, it will lead to a higher wind velocity at the pedestrian level, and consequently reduce the PET value.

The results of this simulations proved that the H/W ratio is influential on the outdoor thermal comfort. Of the environmental parameters, air temperature and T_{mrt} are affected in particular. High H/W ratio in deep urban canyons results in the creation of large daytime cool islands. By day, the lower part of the canyon is in utter shade and consequently the air is not warmed. Furthermore, the deep canyon is mostly isolated from the warm air above that passes over it, as opposed to shallow canyons. Therefore, the difference in the depth of urban canyons within a city creates intra-urban temperature variances.

The simulations indicated that the cooling effect on the air temperature tends to be more significant in canyons with H/W ratio of equal or greater than 2. Daytime PET decreased with increasing H/W ratio, which agrees with the findings of similar studies, especially those with actual field measurements, such as (Ali-Toudert, Djenane, et al. 2005) and (Johansson 2006).

The simulations demonstrate an extensive variation in PET values between the deep and shallow canyons. In summer, when solar elevation is high, shade is limited to a narrow strip adjacent to walls or is completely absent. However, shallow canyons might be more comfortable to pedestrians in winter situation, as they offer more sunny areas. Winter discomfort in canyons with higher H/W ratio could be compensated by suitable clothing, nevertheless total absence of solar radiation at pedestrian level exacerbates thermal discomfort.

Street orientation, also affects human thermal comfort. North-south streets generally have a better thermal situation in comparison to the east-west canyons. However, the effect of the 30° rotation of the street grid is more significant in east-west streets, on the contrary to their north-south counterparts where this influence is negligible. Nevertheless, this difference in temperature of crossing streets is much lower in reality because of the street influences and mixing of the air between streets with different orientation.

Yet, as solar radiation is the most important determinant of thermal comfort in this climate, H/W ratio again becomes a central variable. In compact neighborhoods, where solar penetration is slight, street grid rotation no longer affects pedestrian thermal comforts. On the other hand, in dispersed neighborhoods with low H/W ratio, this rotation is more influential.

Considering the urban materials, while thermal conductivity was indeed ineffective on the thermal comfort index, reflectivity demonstrated a tangible effect. This is in contrast with the findings of Johansson (2006) in his studies on Fez, that reflectivity values of façades and the ground had an insignificant impact on thermal comfort. This difference in results maybe because of stronger solar radiations in Kerman. However, this effect is smaller than that of H/W ratio and street orientation. Although higher reflectivity results in lower surface temperatures, mean radiant temperature (T_{mrt}), increases, therefore thermal comfort deteriorates. It is argued that maintenance of light colors is difficult in hot and dry climates because of the dust. Furthermore, colors that are too bright may cause glare problems.

A deviation in the plot coverage patterns proved to be influential on the thermal comfort in the afternoon hours. As mentioned in the previous chapters, the partition wall of the courtyard mostly constructs the northern boundary of the east-west street canyons, which is typically 3 meters high. If the building coverage changes in a way that building mass occupies southern parts of the northern block, then higher heights of the building will provide shade for a longer duration. And since this shade only comes into effect in the afternoon hours, there is no effect on the thermal comfort before noon. Higher partition walls or provision of shading devices can achieve the same effect.

Balconies and trees also demonstrate a positive impact on PET values. While balconies are only effective through provision of shadow, trees also reduce air temperature through evapotranspiration. Moreover, although solar radiation may penetrate through the crown of a tree and diminish the shade underneath, as they are located farther from the base of walls into the street, they cover a much wider area with their shade. Of course, this all depends on the type and size of the vegetation used. However, apart from the peak radiation hours, trees improve longer periods of time.

All in all, if the pedestrian pathway is located in between the rows of trees and the building walls, they will complement each other, creating better thermal comfort situation over longer periods.

10.2. Urban design guidelines for hot and dry climates

Presented in the following are proposals for street designs in Kerman, which consider human thermal comfort in the future climate. Although they are based on the simulated studies, current urban design practices have also been taken into consideration.

In this research, Kerman is a representation of Iranian cities in hot dry climate and the results can be generalized to most of them, which are dispersed and low-rise cities.

According to these results, provision of shadow is critical in thermal comfort situation of summer time. Canyons with high H/W ratio lead to a more comfortable environment. However, since these canyons have a poor thermal condition in winter, some streets should have lower H/W ratios. Nonetheless, as adaptation to colder temperatures is easier and since the summer season is longer, the majority of the street should be designed for proper summer comfort.

Yet, in order to provide thermal comfort on a larger scale, i.e. neighborhood scale, a combination of streets with diverse H/W ratios is advised. Preferably, north-south canyons, where the thermal situation is comparatively better, should have a H/W ratio of equal or greater than 2. Deeper canyons with H/W ratios higher than 4 are desirable for east-west oriented streets.

Making the streets narrower and increasing the heights of buildings are two ways of increasing the H/W ratios. Each of these practices has its own cons and pros and they should be used hand in hand. For example, narrower streets may disturb motor traffic, and high buildings may result in privacy issues. Therefore, all these issues need to be considered in the design process of urban streets.

In order to increase shade for pedestrian thermal comfort, front setbacks should be banned. In streets with lower H/W ratios than suggested above, shading devices such as balconies, colonnades and shading trees should be foreseen to provide shade around midday. Deciduous trees are suitable for these cities, as they block solar access in summer and allow it in winter.

Although pedestrian thermal comfort is not constituted only by radiation, these studies prove that the PET as an indicator of thermal comfort is affected heavily by the reflectivity level of the building materials. As mentioned earlier, higher reflectivity leads to lower surface temperatures and more re-radiation into the environment. While this lower surface temperature leads to lower convection and thus better thermal condition, these studies show that re-radiation affects thermal comfort on a larger scale. Therefore, building materials with lower reflectivity should be promoted. Recently, aluminum cladding has turned into a common trend in design of commercial and office buildings. Glazed and glossy stones are also very common in residential structures. These materials must be substituted with other materials with suitable properties, at least in areas near to pedestrian pathways.

Current urban regulations in Kerman do not allow most of the proposed street designs. Subsequently, changing the codes to permit higher H/W ratios for streets would be necessary. Particularly, higher building heights and projecting upper floors should be permitted and promoted. These changes in the urban codes would lead to a more compact urban design and hence a more efficient land-use.

Although vernacular architecture is equipped with climate regulating mechanisms, as the climate in this arid area is so harsh, passive design strategies may be insufficient to ensure the required thermal comfort. However, these strategies will extend the time, during which outdoor thermal conditions are comfortable, therefore promote longer and more frequentation of public open spaces.

It is widely accepted that a redesign of a certain environment has a strong influence on the thermal bioclimate. Fröhlich and Matzarakis (2013) demonstrate that in their specific case, reduction in shading had the most significant impact on the thermal comfort. A reduced shading leads to an increase in the areas exposed to direct solar radiation, which in turn increases PET in these areas. Thus during cold and cool periods, subjects enjoy more comfortable conditions. Nevertheless, in this situation, thermal stress increases under hot conditions in summer. A compromise should be made between the thermal situations of two seasons.

10.3. Energy conservation and consumption

Although the focus of this research was on adaptation to climate change, promotions of renewable energies and decrease in energy consumption have also been considered as mitigation strategies, because they receive massive attention in the German projects. A change in the energy consumption pattern, not only mitigates the climate change through reducing further strains of greenhouse gases on the atmosphere, but also it can be considered as an act of adaptation to climate change, since it reduces the reliance of the citizens on fossil fuels. Especially in the wake of Peak Oil, this fact is even more significant.

The studies on the current status of renewable energy production in Iran proved that while there is an enormous potential, especially for solar energy, these energies have been neglected. This research probed the financial feasibility of production of renewable energies in Iran. In case of wind energy, within the limits of Kerman city, there is not enough potential for a sound financial investment. As mentioned before, although wind might not be a reasonable source of electricity, still it can be used for pumping water, both in private gardens and public parks and facilities.

Solar energy is much more promising, both as a source of heat for domestic and industrial purposes and electricity. However, considering the current financial situation and the lack of government support in this field, private investment in renewable energy production is out of question. Cheap fossil fuels and the absence of reasonable Feed-in-Tariffs and other motivating official initiatives eliminate the chance of small-scale clean energy production.

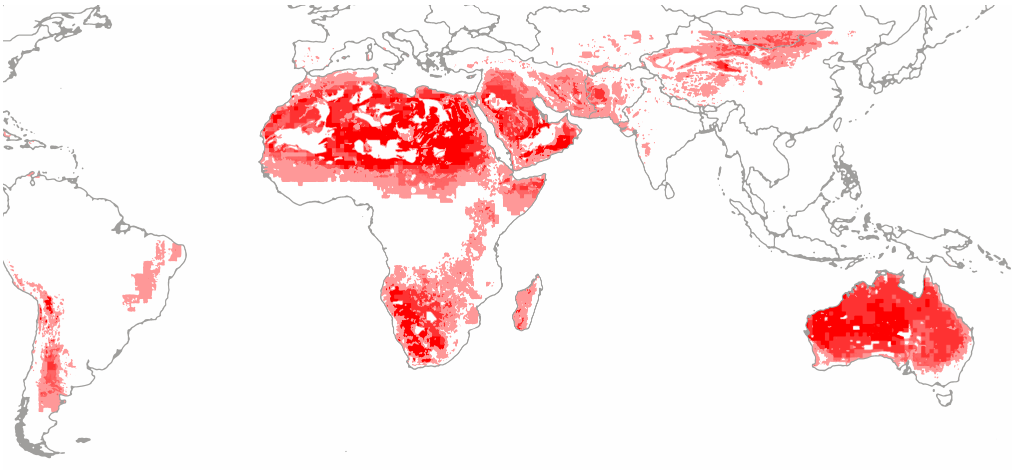

Figure 104: Suitable spots for Concentrating Solar Thermal Power (Source: (Desertec Foundation 2011))

While local investment in Iranian renewable energy sector is not practical at the moment, international investment seems to be very plausible. Some international projects, i.e. Desertec, seek to invest in renewable energy production of high potential regions, aiming to export the energy to markets with higher values, i.e. Europe (Desertec Foundation 2013). In the feasibility studies of the Desertec project, Iran has been identified as a suitable place for Concentrating Solar Power (CSP) (Figure 104). However, involvement in international projects like this needs a well-established international network of relations, which does not exist at the moment.

The Iranian nuclear program has been the source of controversy during the past decade. While Iran claims this program is only for production of power and research purposes, the international community believes that the production of atomic weapons is the main goal of the Iranian regime. However, after years of sanctions against Iran and rounds of talks and negotiations, in November 2013 Iran and the P5+1 countries reached a temporary agreement. According to this agreement, Iran will reduce Uranium enrichment and in return, the international sanctions will be weakened.

International investment in the renewable energy sector of Iran could be an important part of the settlements between Iran and P5+1. The international community could offer to invest on clean energy production in Iran, which could lead to a win-win situation. The Iranian government would have no more excuse to pursue their nuclear program, and it could be an incredible national source of income.

During the past recent years, the trends in energy consumption of the average household have changed significantly. This change, which is quite observable, is both in the choice of energy carrier and the amount of energy consumed. However, here also financial motives are the main driving force.

In 2009 the Targeted Subsidy Act was enforced in Iran. The aim of this law was to remove the direct and indirect subsidies and pay them directly to the heads of families in cash. The government argued that this law would result in a more justified distribution of national resources and income, as the poor already could not afford or did not need to buy government subsidized materials and services. The removal of subsidies was done in several stages, starting from the energy carriers, water and bread. Consequently, the prices increased significantly; Automobile gasoline, natural gas and CNG had the most noteworthy increase in this period. Although all the citizens received the equivalent of the subsidies in cash, most of the urban population had to spend more than they used to. While the rural population and the nomads enjoyed a better fiscal situation after this act because of their lower consumption of materials and energy, it had a negative financial impact on the lives of urban dwellers.

Zeynali (2013) performed a comprehensive research on the effects of this act on lives of urban citizens. He argues that while the urban poor is not feeling a great difference, the middle and high-income households are experiencing massive changes in their lives. He demonstrates that in order to offset the negative impacts, they have to change their lifestyles accordingly. Reduction in energy consumption is the first step, according to Zeynali, but there is no official report supporting this claim. Although necessary changes in lifestyles have begun, still there is a long way ahead of the citizens to leave the culture of cheap energy and adapt themselves to a more climate friendly way of life.

Once again, it seems that financial matters are the most effective means in hands of policy makers. In fact, the government should promote the local production of renewable energies through introduction of attractive FiTs, reduced customs taxes of the related appliances and raising the awareness of the general public to attract more private investment in this sector. In order to promote climate-conscious lifestyle changes, energy conservation can be endorsed by precise alterations in energy prices and official subsidies on energy carriers. However, the general awareness of climate change will increase the public acceptance of these policies.

10.4. Adaptive capacity in Kerman

This research demonstrates that the current adaptive capacity in Kerman, and in other Iranian cities in hot and dry climate, is generally very low. However, based on the experiences of traditional Iranian urbanism and successful adaptation strategies in similar contexts, there is a massive potential to increase adaptive capacity and urban resilience in face of a changing climate.

Similar to the limits to adaptation in Kerman, Adaptive capacity is influenced by economic issues, technological matters, and social factors, such as human capital and governance structures. Heavy reliance on fossil fuels, both in transportation and as a source of energy for space heating, limits the capacity of the citizens to adapt to the future climate.

10.5. Limits and barriers to adaptation in Kerman

There are significant barriers to implementing adaptation strategies in Kerman. These limits are mostly technological, financial, cognitive and behavioral, and social and cultural constraints.

These limitations can be categorized into three main groups:

- Technological limitations:

  Modern technology is unlikely to be transferable to this context. These technologies are either blocked because of the sanctions or too expensive to be financially viable.

- Informational and cognitive barriers:

  As mentioned in chapter 2, the decision-making process concerning climate change is influenced by uncertainty about future climate change, individual and social perception of risk, opinions and values. Definitely, adaptation responses to climate change can be limited by human cognition.

  Moreover, perceptions of climate change risks are differing. Increased concern about one type of risk leads to a lower apprehension about other risks. In this case, concerns about earthquakes overshadow considerations about the impacts of climate change and adaptation. In most cases, the risks that threaten a region are prioritized. The adaptive activities are then focused on those considered to be the most significant at that particular point in time. At the moment, most of adaptation activities in Kerman are dedicated to earthquake, as it is perceived the main threat against human well being in this city.

Furthermore, a lack of experience of climate-related events inhibits adequate responses. In case of Kerman, there is a gap between the older generations that had the experience of climate friendly urban development and the modern one that relies heavily on fossil fuels for regulating the climate of their environment. This experience can be both previous exposure to a certain climatic event or general knowledge on the adaptation procedure against that particular threat.

- Social and cultural barriers:

  Cheap and abundant fuel is embedded into the local culture extremely deeply. This has created an environment that does not accept adaptation strategies easily. Moreover, the urban poor and immigrants with access to fewer resources are not only more sensitive to the threats of climate change, but also have less chance of adapting themselves to future circumstances.

Lack of general awareness, absence of necessary funds and infrastructure, assignment of low priority on the threat list, rigid and outdated national regulations, international sanctions and other issues all pose barriers against adaptation to climate change in Iranian cities, particularly Kerman.

10.6. Urban farming and groundwater

Unfortunately, Kerman does not enjoy a decent sewage collection and disposal system. Although this network has been under construction in the past couple of decades, there are reports that this project has had a mere 25% physical progress (Fars News Agency 2014). Traditional sewage pits are still used in the majority of Iranian cities and a few of the large structures, i.e. hotels, may have a septic tank before depositing the waste into the pits. Moreover, the physical location of Kerman and the provision of drinking water from far away sources have led to a gradual increase in the ground water level. The water level in some parts of the city is merely 4 meters below the ground level, which is not common in similar cities. This raised water level has created both potentials and threats. While construction may be hassled, water extraction has been made easier. Although this water is mixed with sewage and is not safe for human consumption, it can be used in irrigation of urban vegetation. This water can be used in promoting urban farming, both by public initiatives and private entrepreneurs.

Flatbed roofs create suitable surfaces for urban farming, however vegetation types and varieties should be selected wisely according to the local climate. Furthermore, the already existing canals along the sidewalks have the potential for denser vegetation with appropriate shrubs and trees.

Regarding the four scenarios put forward by Newman and his colleagues, the gated community will not be the case in Kerman, as gated communities do not exist in general in the Iranian context. Residential complexes are an exception of this fact. Furthermore, since all the cities report to the same authority (the central government), it is highly doubtable that a gated city will become a refuge for wealthy people.

As the current agricultural technology in Iran is completely based on petroleum, when the peak oil is reached, agriculture cannot strive as before, therefore cities will not be able to sustain themselves on locally produced agricultural products. In case of Kerman, a desert city with harsh climate, conventional farming is not a probable alternative.

If enough policy changes are not implemented in Kerman, citizens will choose to move to other cities in the country, which have a higher relative quality of life. These destination cities may be the small walkable cities where traditional agriculture is the basis of urban economies.

10.7. Climate related policies in Iran

Extensive review of the Iranian official rules and regulations in the building sector has proved that adaptation to climate change has not been mentioned or considered directly at all. However, recently a new trend has been growing in the governing bodies on the need to reduce the overall energy consumption in the country. The motives behind these efforts are mainly financial, namely the rising costs of energy and fuel, and to some extend technical, due to the increasing energy demand and the lagged development of energy production sector.

Energy saving has been mirrored in the building regulation and codes. The 19th chapter of the National Building Regulations, published in 1991 for the first time, is dedicated to reduction in energy consumption. In the forewords of this chapter, the authors claim that high energy consumption in the building sector- which is more than one third of the total national energy consumption- is mostly a *cultural issue*, since "*the real value of energy is never understood*" because of the direct and indirect subsidies on energy carriers (Ministry of roads and urban development 2011).

In this chapter, several guidelines have been *recommended* in building design in order to reduce energy consumption in building heating/cooling through *taking advantage of the natural climate*. However, while these guidelines are only mandatory in the construction of new buildings, the official authorities do not control their practice effectively. Apart from the general heat insulation the following guidelines have been endorsed:

- Building orientation:
  Proper building orientation should be foreseen, in order to take advantage of the solar energy, to ensure proper ventilation and incorporate cool breezes during summer, and to block unwanted wind currents through out the year
- Urban form:
  The ratio of a building's crust to its floor area has a direct relation with its heat conductivity. Therefore it is recommended to increase urban density in areas with high energy demand (according to Iranian standards) and to reduce it in warm and moist environments and in areas with high cooling demands. In such areas building design should provide natural ventilation in all inner spaces.
- Space configuration:
  In the architectural design of a project, secondary spaces (those that are not used around the clock) should be placed between the main spaces (occupied throughout the day) and outside, therefore acting as heat insulation. Main spaces should preferably be located at the southern side of the building to ensure maximum solar heating.
- Transparent tissues:
  Transparent tissues, i.e. windows, are a main source of heat loss during cold periods; therefore thorough attention should be paid in their design, both in terms of size and materials.

10.8. Consideration of climate in Iranian urban design paradigm

As mentioned before, in recent decades climatic conditions have been ignored in designing buildings and cities, however this is not a product of the fact that the effects of climate and natural environment on the built environment are not investigated in this context. In fact, there is a comprehensive list of literature on this issue, alongside a rich history of climate proof architectural techniques. Climate friendly design has lost its spot on the priority list of designers and architects along the way. Neglecting climatic conditions is, on one hand because of abundance and low cost of fossil fuels, and on the other hand a product of different limitations in design.

It has been argued that financial matters play the most important role in the design process (Pourdeihimi 2011). For example, for designing low cost housing units even for the middle-income class, maximum advantage of the limited resources (land) should be taken, which leads to several issues in design.

The absence of climate consideration in urban design and architecture has resulted in the need to incorporate more mechanical technologies in order to improve thermal comfort indoors. Serious consequences on climate and environment, such as air, water and soil pollution and global warming, are expected with this increased reliance on energy.

The existing urban design guidelines in Kerman are vague and imprecise. Since these guidelines are general for a larger region, they do not define or quantify design aspects such as building heights or space between buildings. These codes are often general in character and not always based on research. These guidelines should be adjusted to local conditions, including climatic factors. However, as Johansson (2006) argues, vagueness in urban design regulations may be a result of the absence of research on the actual effects of urban design on the microclimate.

Study of urban regulations in this region reveals that climate is rarely considered in urban planning and design, and urban codes and guidelines are poorly adapted to the local climatic conditions. Sometimes, these codes even can act as obstacles to climate-conscious urban development.

There are several reasons for the absence of climate considerations in the development of Iranian cities. Economic issues constitute a prominent part of these reasons. Private investors and non-governmental enterprises fund the majority of the residential developments within the limits of the city. As the investors expect the most amount of return on their investment, they will do whatever it takes to lower the costs of the project and to increase the profits. For example, they tend to use the cheapest building materials and plan to produce as much floor area as possible.

There are two types of building codes in Iran. Some are taken very seriously, and certified engineers control them at each stage of the construction. A building will not receive its necessary documents, should the controller reject the integrity of those building codes. A good example of this type of codes is the regulations for building fortification against earthquakes. As mentioned before, several destructive earthquakes have struck Iran in the past years. The massive devastations created a suitable *policy window* (See chapter 2) to implement new and improved building codes. The "2800 Code of Practice", which was fully enforced after the Bam earthquake in 2003, is an example.

The second types of building regulations are those that *recommend* or *discourage* certain aspects of the built environment. In fact, many of these regulations are quite vital for a sustainable development, but still there is no obligation to put them into practice. Most of energy conservation practices belong to this group. For example, while it is recommended to adopt multiple glazed windows in construction of residential buildings to minimize the amount of energy loss, there is no obligation on the type and quality of windows installed in buildings. And since double glazed windows are much more expensive than the regular single glazed windows, they are rarely used.

The local municipalities do not have enough authority to enforce new building codes, unless they are supported by the central government and legislative organizations in the field of construction.

Figure 105: Culture of Cheap Fuel; Water heater is installed in the balcony (Source: Author)

As the consequences of climate change in Iran happen over a rather long period of time, instead of instantly, it is difficult for the general public and the unaware decision makers to grasp the magnitude and significance of these consequences. Therefore, the chance of a policy window is pretty slim. Hence, in order to create enough legislative support for the enforcement of these ignored building codes a paradigm shift is necessary. Raising the awareness of climate change within the general population will create an atmosphere, suitable for adoption of adaptation strategies. It will also help to depart from the culture of cheap energy, through a change in lifestyles.

As discussed before, although geographical and climatic analyses are the first steps of the design process of urban and regional projects, there is no control over the actual implementation of these considerations into the final projects. Therefore, it is vital to improve the design processes, and make them more transparent, so that deliberation of climate in urban design is insured.

Johansson (2006) argues that the lack of user-friendly tools to predict the effect of urban design on the microclimate is another constraint against consideration of climate issues in urban design. While Eliasson (2000) points out the access of Swedish planners to tools and climate consultants, in Iran as a developing country these tools and services are not conventionally available to planners and designers. Promotion of these tools, i.e. microclimate simulation softwares, might also be a significant step towards awareness building within the community of urban planners and designers.

Last but not least, decision-making processes should be made more transparent, and allow outside investigation and scrutiny to insure maximum performance of the outcome, especially for building codes and regulations. A broad restructuring of these codes to accommodate climate conscious urban development is of paramount significance.

10.9. Suggestions for future studies

There were several delimitations in the design of this research due to numerous factors explained earlier. Each of these delimitations creates a unique opportunity for further research. This research focused on the effects of street design on outdoor thermal comfort during hot season as an adaptation opportunity against climate change. It would be interesting to conduct a similar research under alternative conditions. Focusing on winter thermal comfort, analyzing alternative urban forms and densities, deeper research on thermal comfort in urban public spaces and suitable building materials are all topics that deserve further investigation.

Furthermore, user-friendly tools that enable designers and decision makers to experience the influence of their decisions on the built environment should be developed and promoted.

Proper vegetation and tree types, which are suitable for plantation in these climates, both in terms of the shade they offer and their water demands, should be identified and introduced to the general public. Other public policies for endorsing urban greening should be adopted as well. Moreover, as mentioned earlier, detailed feasibility analysis on renewable energies and their deployment in the Iranian context is vital. Alternative means of transportation in this context, also call for more in depth exploration.

As mentioned in previous chapters, private land ownership in Iranian cities created hassles against urban development programs. Research on this matter and the possible changes in the implementation of urban renewal plans is also essential.

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Appendix I

Table 30: Metabolic rate and mechanical efficiency for different activities (Source: Fanger 1972)

Activity	Velocity of movement v_F in km/h	Metabolic rate in relation to 1 m^2 of body surface M/A_{Du} in W/m^2	Mechanical efficiency η $\eta = W/M$
Sleeping		41	0
Sitting, still		58	0
Standing, relaxed		70	0
Walking:			
on level ground	3,2	116	0
	4,8	150	0
	6,4	220	0
upwards			
slope 5 %	3,2	175	0,10
15 %	3,2	270	0,19
25 %	1,6	210	0,20
Gymnastics		175 to 230	0 to 0,1
Playing tennis		270	0 to 0,1
Driving (inner city)		170	0
Heavy work (e.g. road construction)		250	0 to 0,1
Office work		110	0

Appendix II

Table 31: Albedo and Absorptivity of typical urban surface materials (cited in Johansson 2006)

Surface	Short-wave reflectivity α	Long-wave emissivity ε and absorptivity
Dark, wet soil	0.05	0.98
Light, dry soil	0.40	0.90
Long grass	0.16	0.90
Short grass	0.26	0.95
Asphalt	0.05-0.20	0.95
Concrete	0.10-0.35	0.90
Brick	0.20-0.40	0.90-0.92
White paint	0.50-0.90	0.85-0.95
Red, brown and green paint	0.20-0.35	0.85-0.95

Table 32: Volumetric heat capacity, thermal conductivity and thermal admittance values of typical materials (Sources: (Johansson 2006) and (P. Fanger 1973))

Material	Heat capacity ($kJ/m^3°C$)	Thermal conductivity ($W/m°C$)	Thermal admittance ($J/m^2S^{0.5}°C$)
Sandy soil, dry	1300	0.30	600
Sandy soil, saturated	3000	2.2	2600
Clay soil, dry	1400	0.25	600
Clay soil, saturated	3100	1.6	2200
Asphalt	1900	0.80	1200
Brick	1400	0.70	1100
Concrete	2100	1.5	1800
Natural stone	2300	2	2100
Softwood	1400	0.14	400