Urban Heat Island adaptation through Urban Planning and Design: the struggle of the city of Los Angeles

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Abstract

Urban heat islands (UHI's) have major impacts on the livability and sustainability of our cities, particularly in the future. Although the effects and impacts are generally well documented and understood, corresponding adaptation processes have not yet lead to sufficient results, especially in the fields of urban planning and design. It seems that UHI management is an example of the knowledge-action impediment; well-founded, applicable and valuable knowledge on the UHI phenomenon is currently hardly used in the planning and design of our cities.

A review of primarily environmental and climatological literature shows that the UHI phenomenon is characterized by a high degree of complexity, with a lot of separate processes and factors affecting urban temperatures. The Urban Energy Budget is an important contribution that provides insight in the main cause behind the phenomenon; it is human-induced and driven by urbanization processes. This statement means that the adaptation process should take place in the fields of urban planning and design, directly influencing the built environment.

With the step toward relevant UHI adaptation measures, a connection between the fields of urban climatology and applied climatology is established. The measures are presented in a conceptual framework that serves as basis for the case study in the city of Los Angeles. This case study reveals the contemporary UHI adaptation in both the policies and practices of urban planning and design in the city. On the policy side, the study shows a non-structured framework of policies with primarily indirect linkages between the real causes of UHI effects and existing policies; relevant activities are fragmented among different departments, companies and other involved parties. In the planning and design practice, professionals do pay attention to UHI effects and they are aware of the planning/design adaptation requirements as well. However, they have not the ability, power and will to implement them in their daily practices.

Adaptation of UHI effects require a radical change in the way buildings, streets and entire neighborhoods are planned, designed and lived. With regard to the findings in the case study, two major observations explain the difficulties in the UHI adaptation process. First, urbanization processes and economic growth negatively interact with each other because they are the major force behind both the formation and adaptation of UHI effects. Second, the UHI phenomenon is highly complex and falls within various fields of study and management. In order to manage the effects in a successful way, a level of interdependency between various departments, companies or individuals is thus required; an interdependency that is currently absent in the city.

Reviewing on the knowledge-action impediment, this research showed that an improvement of the awareness for the urban climate and communication between different stakeholders is needed in order to achieve some form of sustainable urban development. In addition, the most important and crucial role in adapting to these kinds of environmental problems lies with the individual; the urban planner, designer, engineer or politician. The urban professionals have the power to create larger structures then themselves; addressing complex environmental problems and protecting our cities in the future.

Acknowledgements

Writing a thesis is very much like a heat wave; the preparation phase is long and filled with anxiety, you never know how long it will take and at one moment it is suddenly all over. On the other side, it provides an unlimited number of opportunities to meet new people, interact, develop yourself and enjoy the final product you worked on so long.

This particular project gave me so many opportunities because it was written as part of the Network for European and United States Regional and Urban Studies (NEURUS), this research is therefore mostly conducted in California. Although a continental transfer during the project has some practical disadvantages, the participation in Neurus program was very interesting and a valuable part of my master's degree. Therefore, I would like to thank Paul van Steen as international Neurus coordinator and the other affiliated Neurus staff members and students for their efforts in the past year.

Conducting research in a new and foreign environment can be very challenging, but the staff in the department of Planning, Policy and Design helped me find my way and showed me the right direction on many occasions. My special thanks go to Janet Gallagher and professor Scott Bollens, who was besides my supervisor a fantastic guide in discovering the beautiful life in Southern California.

In addition, I would like to thank Terry van Dijk for his flexibility and efforts in putting the pieces of this research together. The continental transfer was literally halfway the research project, his comments were challenging and produced this work out of a plane full of information. Finally, I truly hope the findings of this research will help the interviewed urban planning and design professionals in their work in the city of Los Angeles. They were not only very helpful and kind in contributing to this project but also showed very interesting parts of the urban planning and design practice in the United States.

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Chapter 1

Introduction

Science is organized knowledge. Wisdom is organized life.
Immanuel Kant (1724-1804)

1.1 Research Background

Modern population dynamics change the way we live in the entire world. According to the United Nations [1], approximately 5 billion people will live in urban areas by 2030, which is almost 60 percent of the entire population. In addition, this growth is exceeded by the increase in number of households, which means the average number of people per household is declining. So, our cities will expand even more in the future, putting more pressure on the available urban space. The ongoing urbanization patterns have a substantial impact on the way our cities are planned, built and lived. The transformation of rural to urban areas has several human-induced consequences, for example the loss of vegetation or water resources [2]. It influences the morphology and energy budgets of the urban area as well, which tends to lead to higher temperatures in the city relative to the unbuilt surroundings [3, 4]. This is the essence of the Urban Heat Island (UHI) phenomenon. The English meteorologist Luke Howard was the first to study the phenomenon; he discovered a significant increase of temperatures in the inner city of London in the year 1818 [5].

For a long time, UHI's did not get much attention from science or politics. This changed in 1971, when the Club of Rome presented their Limits to Growth. The report was the first to address the impacts of population growth, which made UHI's one of the clearest impacts of human-induced environmental change [5]. In general, the report resulted in a fundamental discussion about the reality of climate change and a search for scientific evidence to proof the human influence in it [6]. In the case of UHI's, the formation and impacts were substantially studied and analyzed, till it became clear that an increasing fraction of our population was exposed to the atmospheric environments of cities.

In the last two decades, the debate on climate change and UHI's has undergone major changes, when politics and society started to pay more attention to the issue. Especially the measurement of the impacts and the question how to deal with them have dominated the global discussion, resulting in substantial new amounts of information on mitigation and adaptation measures. However, because policy makers and society requested an appropriate reaction to the impacts of climate change and UHI's, the measures alone were not enough. The perspective shifted from a natural scientific to a multi-disciplinary approach with more attention for the production of knowledge and communication between scientists, planners and policy makers [6], in order to develop sustainable places. As a result, urban planners and designers need to deal with the consequences of this debate; new amounts of information, the demand for complex, sustainable places and more influence from politics and society.

However, in the new debate, the UHI phenomenon was overshadowed by other effects such as sea-level rises or global warming. This is perhaps not surprising, considered the catastrophes in for example Bangladesh or New Orleans, but UHI's should not be forgotten. For example, the recent heat waves in Europe, with thousands of direct causes of death and illness as a result led to a massive national debate. In addition, the impacts on urban water- and energy infrastructures are substantial. Increases in energy demands have several negative impacts on cities and their climates and water resources are under pressure. For example, multiple heat waves in the summer of 2005 pushed the Californian energy supply to its limits, resulting in several supply shortfalls [7]. These and other recent experiences with the consequences of UHI phenomena showed the vulnerability of our urban areas during times of extreme heat.

So, the UHI is one example of several climate change related effects that put spatial planners under pressure; planners face the challenge of using substantial new amounts of information in creating well-planned and sustainable places. In the case of UHI's, scientific, environmental studies produced several theories on how to decrease the negative effects. The important question now is how to use all the new information and deal with the influence of politics and society in creating places that are both well-planed and sustainable, thus how to use the measures in an effective way. To understand this process of developing a particular UHI policy for a city, more research is needed on the specific problem of using all the general measures in a local planning practice. In this way, the negative effects of UHI's can be decreased, ensuring a sustainable development for our urban areas.

1.2 Research Overview

So, urban heat island effects have major impacts on the livability and sustainability of our cities, particularly in the future. The objective of this research is to examine what these effects exactly are, how the adaptation can be in the fields of urban planning and design and how this process is currently evolving in the city of Los Angeles. The main research question is therefore:

> How is the city of Los Angeles adapting to Urban Heat Islands through urban planning and design?

With this question, the research takes effort to address a broader discussion as well that is defined here as the knowledge-action impediment; the struggle to transform innovative, relevant and founded knowledge into corresponding actions. Therefore, the UHI research is a case study of the city of Los Angeles, which is on its turn a case study of the contemporary discussion on the knowledge-action impediment in environmental management. An overview of the research is presented in figure 1.1.

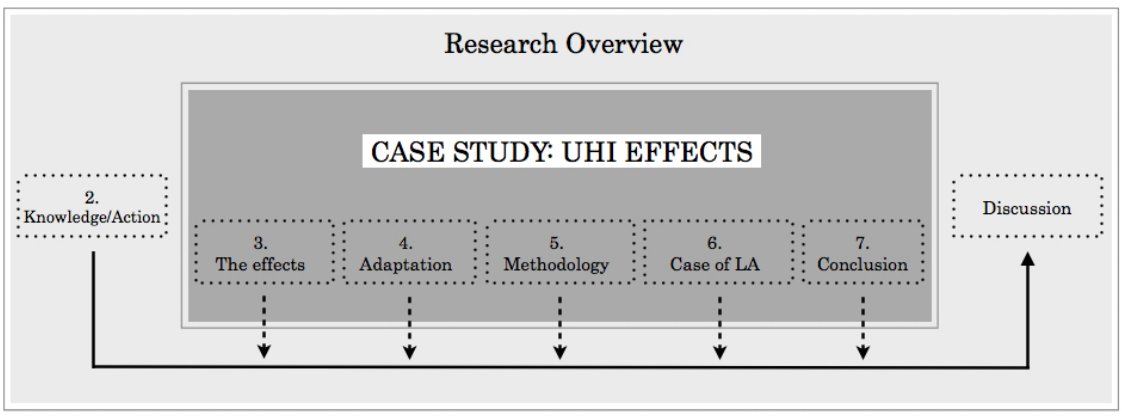

Figure 1.1: Research Overview

The overview shows the different parts of the broader and smaller scope of the research; *Chapter 2* introduces the broader discussion, *Chapters 3 till 6* address UHI's in the city of Los Angeles, concluded by *Chapter 7* and *the Discussion* returns to the broader discussion of the knowledge-action impediment again. The case study of UHI's in Los Angeles contains thus four different Chapters: it examines the formation and impacts of UHI's in Chapter 3, addresses UHI adaptation measures in urban planning and design in Chapter 4, explains the methodology in Chapter 5 and represents the findings of the case study in Chapter 6. Before starting off with Chapter 2, the methodology and innovativeness of the research are introduced first.

Methodology

The methodology of the research can be described as a qualitative single case study with multiple components. Because of the multidisciplinary nature of UHI's, a complexity theory perspective is used to chose, extract, store and analyze the data sources. In practice, this means that the case study focuses on "the three P's": Participators, Policies and Practices. Using insights from complexity theory, three sub-questions are proposed, each addressing one of the P's:

- The first sub-question investigates all the involved actors in the planning and design of the city. In the research, this question is answered in the explanation of the methodology in Chapter 5 and phrased as "Something is happening on a city level; who is involved in the planning and design practice of the city?"
- The second sub-question investigates the current UHI policies in the fields of urban planning and design and phrased as "What is the result of the planning and design activities by the involved parties?" It is answered by examining the role of UHI's in all the relevant plans, programs, incentives, ordinances, strategies etc. This information is then used to represent the case study findings in Chapter 6.
- The third sub-question investigates the individual actions, goals and constraints in adapting to UHI's and is phrased as "What are the goals and barriers of the individual actors behind the involved parties that steer the activities?" The answer to this question lies in the findings from the case study interviews; it aims at discovering if and why urban planning and design professionals use UHI effects in their daily practices.

Together, the answers to the three sub-proposed questions form the core of the findings of the case study and lead to the answer of the research question in Chapter 7. Using the conclusion, the broader discussion of transforming useful knowledge into corresponding actions can be addressed in the perspective of the research findings.

Innovativeness

Although UHI effects form a problem in many cities around the world and they have broadly been analyzed and documented, this research adds substantial new information to the existing knowledge about the occurrence and adaptation of UHI's, especially in Southern California. First, an exact explanation of the formation of UHI's is represented, all concluded in one figure (see also the list of figures, figure 3.3) and explanatory paragraphs. Where many scholars discuss one or two UHI causes or effects, this kind of overview of the formation does not yet exist. Second, this research connects this exact science to applied sciences by bridging the gap between urban climatology and urban planning and design.

The result is a conceptualization of UHI adaptation measures in figure 4.9. Such an overview or connection is totally new, UHI were previously only examined from one of the two sides of the phenomenon. And last, the contemporary occurrence and adaptation of UHI effects in the city of Los Angeles is examined. Existing UHI studies in the city of Los Angeles are either outdated or not very comprehensive; the case study in this research examines the occurrence, impacts and management of UHI's today.

1.3 Reader's Guide

With the important aspects of this research introduced, Chapters 2 starts with addressing the knowledge-action impediment and some developments in the field of environmental management. After this general introduction, Chapter 3 reviews on the current knowledge on the formation, effects and impacts of the UHI phenomenon. Chapter 4 translates this knowledge into adaptation measures in the fields urban planning and design; followed by the methodology of the case study in Chapter 5. Chapter 6 presents the case study findings, addressing the state of UHI adaptation in the city of Los Angeles. The case study ends with a conclusion in Chapter 7 and finally, the discussion on the knowledge-action impediment completes this research.

Chapter 2

The Knowledge-Action Impediment

Knowing is not enough; we must apply; willing is not enough; we must do.
J.W.Goethe (1749-1832)

Introduction

Especially in the field of environmental management it is not unusual that for several reasons, existing knowledge, concepts or approaches are not implemented in daily practices or actions. The case of Los Angeles will examine this problem from a UHI perspective. Therewith, it tries to contribute to the broader discussion on the knowledge-action impediment and make useful recommendations for the city of Los Angeles. Before going into the UHI problem, this chapter reviews on the contemporary developments in the knowledge-action discussion first. During the rest of the research, the information of this Chapter serves as background to place UHI's in a broader perspective. Final comments on this particular topic, using information from this research, will be made in the Discussion after Chapter 7.

2.1 The shift in environmental management

In general, the multi-disciplinary nature of environmental problems forms the basis in addressing the knowledge-action impediment in environmental management. For example, Oke [8] states that "meteorology, climatology, physics, geophysics, geography, biology, ecology, environmental science, hydrology, engineering (civil, mechanical and chemical), building and landscape architecture, building science, town planning, social science and medicine all play important roles in the field of environmental research". He addresses the problem of bringing these different fields together in order to act effectively and facilitate scientific interaction. Unfortunately, his approach of dealing with these issues is very technical; Oke strives basically for a way of standardizing and classifying all environmental aspects. Whereas this approach can be very useful in the more natural aspects of the environment, urban planners or designers are not equipped to respond to these kinds of information. And since the idea behind this chapter is primarily to understand why the management of environmental problems is so difficult, Oke does not lead us the way here.

Without going into the theoretical details of environmental management or planning too much, it is necessary to reflect upon some ideas that form a basis for a new way of thinking about the knowledge-action impediment. Both Friedmann [9] and later de Roo [10] have substantially contributed to the discussion on the theoretical background of environmental planning. In general, they introduce the aspect of complexity in environmental planning, a term that is used to distinguish environmental problems and their management. In this concept, the degree of complexity determines the management strategy and desired outcome. This degree of complexity is measured or assigned by evaluating several characteristics of the problem, focusing on aspects such as the number of involved actors, dynamic state of the problem or relevant policies and regulations. In other words, the focus shifts thus from the problems itself to contextual issues. This is recognized by de Roo [10],[p.89] who states that, in order to determine and deal with this complexity, "(..) the context of environmental issues determines the solution strategy to a

greater extent than before". De Roo introduce herewith a new rationale for environmental planning and management in which the technical-oriented way of standardizing environmental problems is replaced by a context-driven way of environmental management. This context-driven approach forms the basis for explaining why knowledge often not leads to action; the answers lies thus not in the environmental problems itself but in the surrounding contextual issues.

2.2 From knowledge to action

In planning theory, a shift toward the context-driven management of environmental problems is thus happening. This brings us however, besides a theoretical hurray, not that much. In order to address the knowledge-action impediment, a more practical guideline is needed that answers the question why the link between the two sides is so inconvenient. A convincing approach can be found in Eliasson [11]. In her article, she states an hypothesis that climate knowledge has a low impact on the environmental planning process due to contextual issues in the general field. A case study in three Swedish cities tests this hypothesis and addresses the common problems and explanatory variables. According to Eliasson, the following problems and variables occur in the relation between action and knowledge in environmental issues (see figure 6.2):

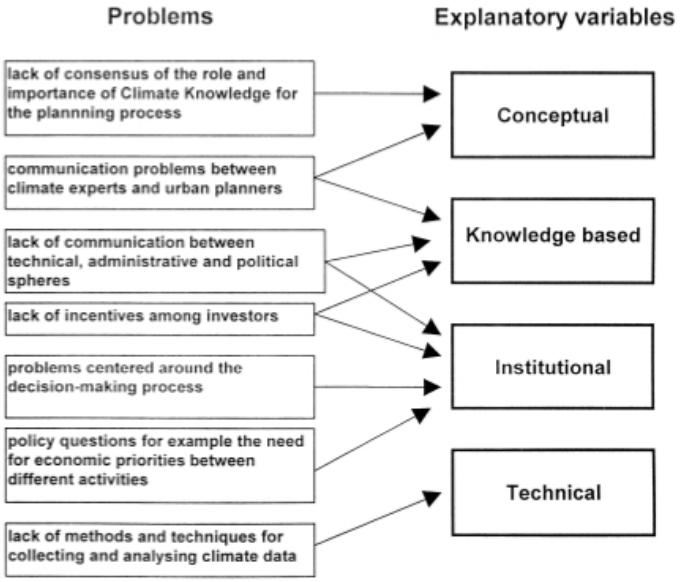

Figure 2.1: Problems and variables in environmental issues
Source: Eliasson, [11]

In addition to Eliasson, Pressman [12] calls for a more philosophical, personal integration of nature and the planned object of space. He states that in order to integrate the natural environment in planning/design, man must "learn from nature how to design climate-responsive urban space, (..) and it is crucial to realize the need for evoking an emotional response and an attachment to place [12], [p.527]. On this basis, he presents three goals in integrating nature and the planned object and therewith bridging the gap between knowledge and action; (1) integration of concepts and techniques, (2) relate physical goals to economic, cultural and biophysical conditions and (3) target objectives in specific problem areas with recognition of a multi-disciplinary approach. These goals represent an underlying thought in the knowledge-action impediment and can be applied to all environmental problems.

It seems that Eliasson has somehow used the previous goals in the conclusion of her case study, because her conclusions follow the same line of thought. Besides that, Eliasson concludes her article with an extremely valuable framework on the issue of bringing knowledge into action. Where many scholars such as Oke [8], Counsell [13] and Capeluto [14] choose a quantitative, superficial approach in explaining the relation between the two aspects, Eliasson presents an in-depth analysis of the problem with practical and tangible recommendations. The framework is presented in figure 6.3 and forms the most important approach in explaining the difficulties in environmental management.

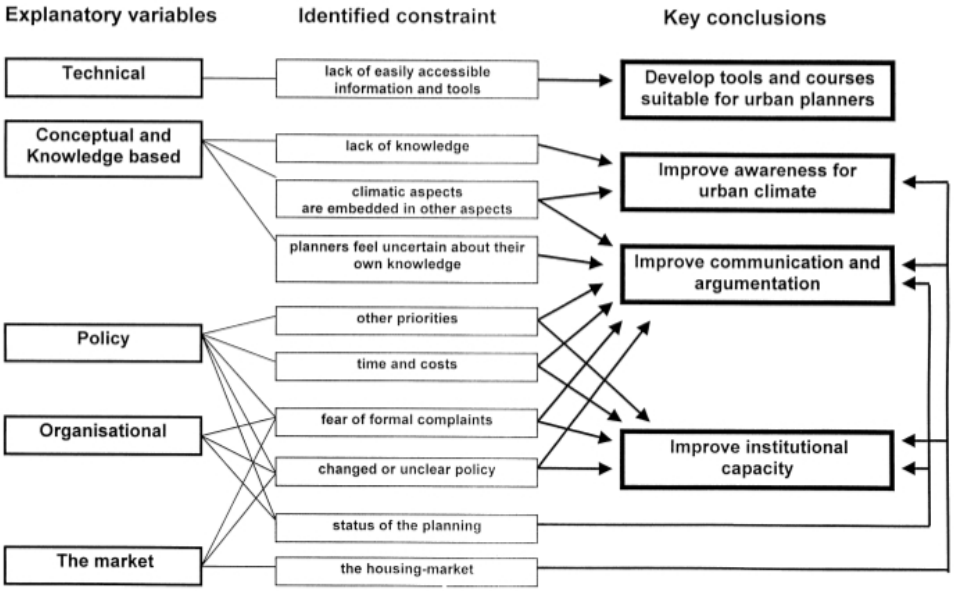

Figure 2.2: Eliasson's environmental management framework
Source: Eliasson, [11]

So, the framework of Eliasson provides both explanatory variables, common constraints and key conclusions. In order to use this framework in this research, it is necessary to make two additional comments. First, the framework is a general representation of the problems in using environmental knowledge in urban planning and design. This means that in case of the UHI's, not every single aspect of the framework is relevant. The objective of this chapter is explaining why, in general, environmental knowledge does not always lead to action. Chapters 6 and 7 approach the exact same issue from a the UHI perspective, a detailed explanation of the de facto problems is given there.
Second, regarding the key conclusions, the problem of UHI's, especially in the US, is highly related to general sustainability issues. In both the political and conceptual/knowledge based variables of the framework, the influence of the concept of sustainability is substantial and cannot be ignored. Although Eliasson does address the issue with "climatic aspects are embedded in other aspects", too little attention is paid to sustainability issues and opportunities. Therefore, an additional key conclusion need to made: *the use of the broader concept of sustainability to address UHI problems.* After all, many other findings of the key conclusions such as the improvement of the awareness or communication can be reached by using the concept of sustainability because this is such a modern and well known concept in the contemporary debate in environmental management. Chapters 6 and 7 will continue on these issues and recommendations.

2.3 Conclusion

This chapter describes the knowledge-action impediment; it explains why relevant and usable knowledge is often not translated into action. In environmental planning and design, the fact that many problems need a multi-disciplinary approach results in many different views on the best management strategy. Where many scholars use a technical-oriented approach, others approach the issue from a complexity perspective, focusing on the context of environmental problems. Since many urban planners and designers are not equipped to deal with the technical approach, the contextual focus leads to a more understandable and relevant explanation. The work of Eliasson falls within this line of thought and is extremely important to this research. Her framework, with explanatory variables, common constraints and key conclusions leads the way in understanding why UHI knowledge is often not used in practice. The framework, nuanced by two comments, serves as background for the rest of the research, especially in the Conclusion and Discussion.

Chapter 3

About the Phenomenon

This town is mere Oven, I feel stifled and roasted
B. Franklin, 1752

Introduction

As ongoing urbanization patterns continue to expand our cities, changes in the landscape occur. Vegetation, water and open land are rapidly replaced by urban infrastructure, which has an impact on the land's surface, resulting in substantial higher temperatures relative to unbuilt areas. This development has led to one of the most broadly studied climatological phenomena of the human-induced environment; the Urban Heat Island [15]. Increased temperatures in urban areas were already reported in the 18th century and appeared ever since. During days of extreme heat in cities, energy consumption increases and severe health issues threaten urban citizens.
It is very important to understand how the phenomenon occurs and what the effects and impacts are, because the rest of the research will be based on this information. To do so, this chapter starts with a short introduction about the exact definition of the phenomenon in section 1. This is followed by a scientific examination of the basis of UHI's in section 2, which is primarily based on urban and regional climates. Using the urban energy budget, section 3 will then provide an overview of the formation of UHI's and section 4 will give a comprehensive overview of the effects of UHI's on urban areas and its surroundings. Finally, the chapter ends with a conclusion in section 5.

3.1 Defining Urban Heat Islands

When talking about UHI's, a variety of thoughts presents themselves. Some people will immediately start thinking about global warming, others think about little islands in the Pacific Ocean, but the largest group has never heard of them. In the contemporary debate on climate change, sustainable development and eco-engineering, the role of UHI's is often very small or completely not there. This lack of attention for the phenomenon can be explained in several ways, all to be discussed in this research, but one of them is definitely the vague and unclear character of it. This section will clarify the exact phenomenon, starting off with the very basics of UHI's.

There are substantial differences in defining UHI's and their effects. The role of urban surfaces, wind patterns and especially global warming is under constant debate. However, there is a common understanding on the fundamental principle of UHI's, which can basically be described as

$$\triangle T_{u-r} \tag{3.1}$$

or as the difference between the urban and rural temperature [2]. In literature, equation 3.1 is defined by Taha [1997, p.99] as: "*urban air temperatures are generally higher than their corresponding rural values, which is known as the Urban Heat Island phenomenon*", which is also shown in figure 3.1.

So, UHI's are basically an increase in urban temperature. Obviously, the question here is what the exact increase is and how it is caused. Measurements and projections differ around the world, because of existing differences in regional climate conditions [16]. For example, the U.S. Department of Energy measured an average increase of 3.3 to 4.4°C (6 to 8 °F) in US urban areas relative to rural areas [17], while Oke [18] states a rise of 2.1 to 5.4°C (4 to 10 °F), as shows in figure 3.1. More recently, Baumann [19] reviewed on different studies and concluded the increase in temperatures is not more then 1 to 3°C (1.8 to 5.4 °F) in cities with more then 1 million inhabitants. In this thesis, we will preliminary use the same increase as Landsberg [3] and Arnfield [20] did, which is 1.2 to 4.4°C (2 to 8 °F), while this is the most accepted and used one [20].

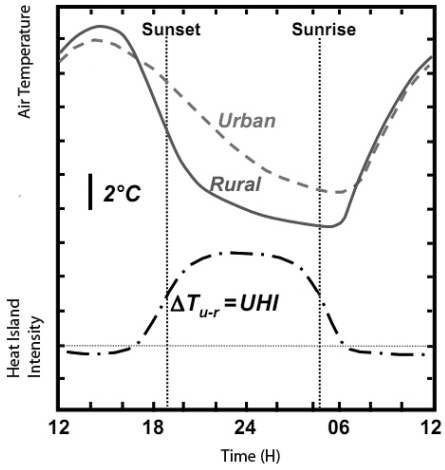

Figure 3.1: Explanation of an Urban Heat Island
Adopted from Oke [4]

Reviewing on a broad selection of environmental and planning literature, we can see the problem of defining the UHI in terms of the thermal effects. It is therefore necessary to study the phenomenon on a local scale, in order to clarify the problem for an urban area, taking specific climatological and morphological circumstances into account. To get a better understanding of these exact causes of UHI's and its relation to urban planning, we will first examine the scientific basis in this chapter.

3.2 The scientific basis

Urban Heat Islands occur in the lowest layer of the atmosphere, affecting regional and local climates [21]. Although some scientists state that UHI's have effects on global temperatures as well, these influences are not yet clear [22]. Later on in this chapter, the relation between UHI's and the global climate/climate change will therefore be discussed in detail.

Urban Climatology

In explaining the processes and effects on a regional and local scale, we have to get familiar with the urban climate first. Accoring to Landsberg [3], the urban climate is not a separate process, but connected to large-scale climate patterns. It is influenced by synoptic weather patterns, geographically determined circumstances[1] and situated in the lowest layer of the atmosphere; the troposphere. So, the synoptic, or large-scale climate is continuously interacting with the urban environment, creating all kinds of static and dynamic weather mechanisms [25]. An important and relevant mechanism is the effect of temperatures on wind patterns, which in turn regulates the pollution concentrations.

[1] For more information, see Boeker [23] or Huggett [24]

Table 3.1: Comparison of Physical Constants for Surface Materials

Surface	Heat conductivity $(cal, cm^{-1}, sec^{-1}, deg^{-1})$	Heat capacity (cal, cm^{-3}, deg^{-1})
Dry Soil	$6x10^{-5}$	$8x10^{-1}$
Wet Soil	$5x10^{-3}$	$5x10^{-1}$
Concrete	$11x10^{-3}$	$9x10^{-2}$

The difference between the rural and urban climate is caused by the difference in the morphology and structure of the land. While rural, or agricultural lands are often characterized by vegetation, loose soil and open space, the urban land is densely built, compact and has an impermeable surface [3]. In table 3.1, the heat conductivity and capacity of two soil types and concrete is shown, to illustrate the differences between built and unbuilt surfaces. It is this difference that is the basis of the first type of UHI's; the Surface Heat Islands (SHI's). Next to SHI's, we can distinguish a second type of UHI's; the Atmospheric Heat Islands (AHI's).
This distinction of UHI's is very important, because the islands influence the general phenomenon and each other in several different ways. In general, surface heat islands work on the surface scale, heating up materials and indirectly increase air temperatures [26]. In contrast, atmospheric islands have a bigger scale and directly increase the air temperature.

3.2.1 Surface UHI's

Surface temperatures have an indirect, but important, influence on air temperatures. They are one segment of the urban canopy layer, influencing the temperatures on the *micro level*. Temperatures of intense sun-exposed surfaces, like pavement or asphalt, can be more than 27 to 50°C (50 to 90 °F) hotter than the air, while shaded surfaces remain close to air temperatures [21]. These increased surface temperatures mostly contribute to urban heat during the night, because they continue to produce heat, preventing the city to cool down.
These types of UHI's are affected by weather conditions, especially solar radiation, and therefore differ around the world [21]. Besides that, micro-scale site characteristics and street geometry have a substantial impact [27] as well, because they influence the exposure to solar radiation. The effects of surface UHI's are mostly presented as thermal images[2], using remote sensing techniques.

3.2.2 Atmospheric UHI's

An atmospheric UHI directly increases air temperatures and is therefore a different phenomenon. In comparison to surface temperatures, the intensity of the atmospheric island varies much less. Temperatures in urban areas tend to be 1.2 to 4.4°C (2 to 8 °F) warmer then the surrounding lands [20]. It is the main cause of the regional effects of UHI's, creating warmer air in urban relative to rural areas [21], which is the scientific definition of UHI's. So, in essence, the UHI phenomenon is defined by its atmospheric presence, and only affected by surface temperatures. This is an important statement for the mitigation/adaptation measures, which will be discussed in Chapter 3.

Any atmospheric UHI exist of two different layers; the canopy and boundary layer, both parts of the planetary boundary layer [27]. *Canopy layer islands* exist in the lowest layer of the atmosphere, where people live, from the ground to the limit of the built area [18]. They result in an increase of air temperatures in streets or little neighborhoods; the local level. A typical phenomenon in the canopy layer is

[2]The NASA is one of the major publishers of thermal images, see http://earthobservatory.nasa.gov/ for more information

the "street canyon"; a deep, narrow street in the city, often highly influenced by UHI's [28]. Factors that contribute to this type of UHI are primarily building materials, urban geometry, albedo modification and evapotranspiration [2]. The exact formation of UHI's will be explained in section 3.3. *Boundary layer islands* occur on a meso-scale, affecting entire cities or even metropolitan and surrounding areas [4]. The boundary layer is the layer that starts at the end of the canopy layer and extends up to the point where the influence of urban landscapes on the atmosphere stops. In most regions, this point is about 2 kilometres (1.25 mile) above the surface. Factors that primarily contribute to this kind of UHI are city form and function, urban geometry, weather/wind patterns and urban energy budgets [2].

Relation between surface and atmosphere

Before examining the formation of UHI's, the exact role of the different UHI's is shortly described first. This is important, because with this reference we can position the factors that shape the UHI's and mitigation/adaptation measures precisely. Both surface UHI's and atmospheric UHI's have a substantial impact on the temperature in urban areas. However, because air tend to mix within the atmosphere, the relationship between the two UHI's is not constant [23]. In other words, surface and air temperatures do not result in the same increase of temperature, as shown in figure 3.2. While surface temperatures vary during the day and especially the night, air temperatures tend to be more constant.

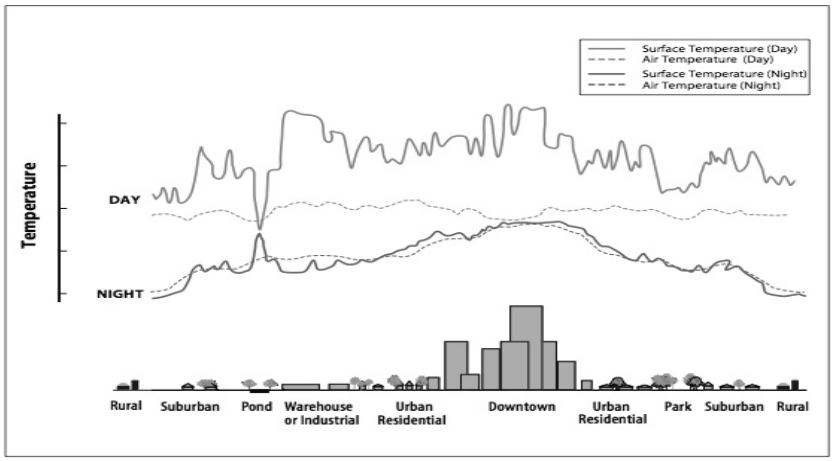

Figure 3.2: Variations of Surface and Atmospheric Temperatures
U.S. EPA (2004) Original: Voogt (2000)

3.3 Formation of UHI's

In literature, the agreement on the general parts, function and effects of UHI's is reasonably convincing. However, the processes behind the general phenomenon are constantly being questioned, researched and rewritten. It is therefore not easy to examine the formation of UHI's. In order to provide such an overview, this section combines several different perspectives on the factors that shape the UHI phenomenon. That is why this section is not an absolute literature review, it is adjusted and produced for this research.

In order to examine all the present factors, this section uses a simple overview of the main processes and impacts on UHI's. This overview (see figure 3.3) is the leading reference for the rest of section and later on, for the mitigation/adaptation measures.

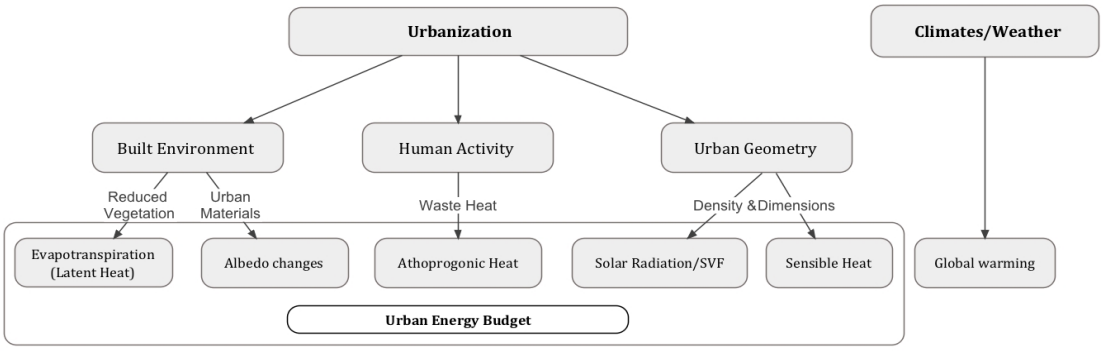

Figure 3.3: Simple overview of formation of UHI

3.3.1 Urbanization and urban changes

In 1973, Oke [15] was the first to relate urbanization and city size to UHI's. Using data and models from previous studies, he discovered a significant relation between the difference in urban-rural temperatures (T) and population size (P) of 10 North American settlements, using a simple empirical model:

$$\triangle T_{u-r(max)} = 2.96 log P - 6.41 \tag{3.2}$$

with $r^2 = 0,96$ and $S_{\triangle T} = \pm 0.7$ °C. Although this model is solely based on ideal circumstances for UHI's, it was a major contribution to the debate on urbanization and UHI's. It was the beginning of a series of studies, all focusing on the relation between urban areas and temperature. Almost fifty years later, the factors that contribute to the formation of UHI's in cities have broadly been researched and documented. Although there is not much agreement upon the exact factors and their behaviour, we can identify three main factors, all resulting from urbanization processes.

1. *The built environment*
   The transformation from rural to urban land is one with many consequences. In the light of UHI's, it has two major impacts. First, when cities expand their limits, natural land is transformed into new built-up areas. The loss of vegetation and natural soils decreases evapotranspiration processes, which is one of the major moderators in near-surface climates [25]. Moreover, trees and vegetation provide shade, lowering surface temperatures [29]. Second, the new urban surface, or urban materials, are better stores of heat [30]; they absorb heat instead of reflecting it. This is caused by the material's thermal emittance, heat capacity and albedo. Albedo, which is derived from the Latin "albus" (white), is the most important one, it is the proportion of light or radiation that is reflected from the surface into the atmosphere [31].

2. *Human activity*
   As cities become larger, more people will influence the urban climate as well. Human urban activity manifest itself in more energy use in buildings and vehicles, which generates more "waste heat". A clear example is the waste heat that the average air-conditioning produces during a warm day. In addition, humans produce waste heat themselves to, leading to higher air temperatures. Taking togehter, these sources are called anthropogenic heat [4].

3. *Urban geometry*
   Another factor that influences UHI's is urban geometry. Especially during the night, the density of a city, defined by the dimensions and spacing of buildings [32], influences the overall temperature. According to Voogt [30] urban geometry has three impacts on the urban temperature. First, the trapping of solar radiation in build-up areas leads to greater absorption of solar radiation. Second, closely spaced buildings effect the Sky View Factor (SVK) and reduce radiative heat loss. Third, urban density influences surface-air exchanges, reducing convective heat loss. The three factors, including the ones from the built environment and human activity, are part of the Urban Energy Budget and will be explained in the following section.

3.3.2 The urban energy budget

The Urban Energy Budget (UEB) was introduced by Oke in 1982 and has broadly been used to examine UHI's effects and impacts. It is basically a simplified equation, describing the roles of surface properties and anthropogenic heat in urban climates [25]. Using the EUB, effects and impacts can be calculated and countermeasures can be tested. It is therefore one of the most important models in describing UHI's. As we will see, all the mentioned factors are part of the equation, which is more recently defined by Taha as:

$$(1-a)I + L^* + Q_F = H + \lambda E + G \tag{3.3}$$

"where a is the solar albedo, I is incoming solar radiation, L^* is net long wave radiation at the surface, Q_F is anthropogenic heat, and H, λE, and G are the sensible, latent, and ground heat fluxes, respectively" [Taha, (1999), p.100].
The UEB is a budget, so it works as a balance. In other words, if the sum of the terms on the left side of the equation exceed the sum of the terms on the right side, temperatures in urban areas will rise. This research will only shortly explain each term; it is not the objective to explain the UEB in detail[3].

Albedo Changes [a]
The total proportion of reflected solar radiation at a particular surface is called Albedo [31]. Although the term itself can be interpret at different ways, in the case of UHI's the specific surface albedo is used, which means "the time, angle and spectrum average of the reflectivities at a particular surface or combination of surfaces" [Taha, 1988, p. 272]. In other words, albedo could be described as the ability of a surface to reflect solar radiation and therefore an important factor in the urban climate. To give an idea about different albedo's, table 3.2 gives an overview of several typical albedo's for different types of surfaces. We can conclude that dark coloured, human-induced, surfaces have a lower albedo then light coloured surfaces, resulting in less solar reflection and thus more heat gain [34]. The exact relation between albedo and urban surface temperature is studied by Connor [35], who discovered a significant higher surface temperature on dark coloured surfaces in residential areas. In conclusion, we can see that especially darker, human-induced, materials and surfaces lead to a lower albedo and gain thus more heat.

[3]More information on the UEB can be found in the extensive research off the authors cited in this section. For example; see [4], [18], [25] and [33].

Table 3.2: Examples of albedo's for different surface types

Asphalt	$0.05 - 0.10$
Concrete	$0.10 - 0.30$
Forest	0.15
Bare Soil	$0.20 - 0.30$
Brick	$0.20 - 0.40$
Green Grass	0.25
White cement	0.78
Snow	0.85

Source: Connor [35]

Solar Radiation/SVF $[I + L^*]$

Besides the albedo, urban geometry influences urban temperatures through solar radiation as well. In general, both albedo and urban geometry determine how the sun's energy is reflected, emitted and absorbed in the urban area [21]. The difference between the two factors is the type of solar radiation that's causing the effect. Albedo changes are affected by short-wave or visible light, which we perceive as light. In contrast, urban geometry effects are sensitive to long-wave or infra-red radiation. Although the absorbed heat through albedo change is dominating the total solar radiation balance, urban geometry is an important factor too [33].

During the day, long-wave radiation is stored in urban surfaces and materials and normally, it is emitted into the atmosphere during the night again. The increase of urban surfaces and therewith urban reflection leads to greater absorption of solar radiation. Moreover, because of the limited open space, the emittance of the radiative heat during the night is disturbed. A well known phenomenon regarding this problem is *the urban canyon*; a small street lined by tall buildings [36]. Although the tall buildings create shade during the day, the radiation that reaches the surface is reflected several times and stored in the materials. Because of the limited access to open air, the heat is trapped and these streets don't cool down during the night.

The relation between urban geometry and heating effects is often expressed in the *Sky View Factor* (SVF). The SVF is an index, describing the visible area of the sky from the surface [21]. For example, a low SVF contributes to heat trapping in streets and could therefore be a street canyon. The relation between urban temperatures and the SVF is addressed by Giridharan [37], who showed a significant relation between nocturnal UHI's and sky view factors in the city of Hong Kong. The SVF index is thus an important influence on UHI's and often used in examining the effects of urban geometry and solar radiation on urban temperatures.

Anthropogenic Heat $[Q_F]$

Anthropogenic heat is in the previous section described as the heat produced by human energy consumption, mostly through vehicles and energy use in buildings. This waste-heat is the thus the product of increased human activity, in terms of mobility or productivity. The exact definition of anthropogenic heat is given by Oke [4], who expressed it as the following formulation:

$$Q_F = Q_{FV} + Q_{FH} + Q_{FM} \tag{3.4}$$

where Q_{FV}, Q_{FH} and Q_{FM} are the heat produced by vehicles, stationary sources (air conditioning) and metabolism, respectively [33]. In formulation 3.4, metabolism is the energy use and expense of the

human body [4]. So, increased human activity contributes in three different ways to higher urban air temperatures.

Sensible Heat $[H]$

Sensible heat is the heat we feel as differences between the surface and air occur [21]. If urban surfaces warms the air above, convection circles arise, which eliminate the extra temperature increase [38]. However, urban density tends to reduce this convective heat loss. The relation between the surface-air exchanges (or ventilation) and urban density is studied by Mills [39] and Bottema [40]. In figure 3.4, the influence of the physical design of cities on surface-air exchanges is shown as a relation between the urban density (fraction of built-up area) and the roughness length Z_0/h. It tells us that, as built density increases, the roughness of a city increases too[5], resulting in less ventilation and thus less convective heat loss. This process takes place in the urban canopy layer and is therefore affected by the proportion of built-up areas.

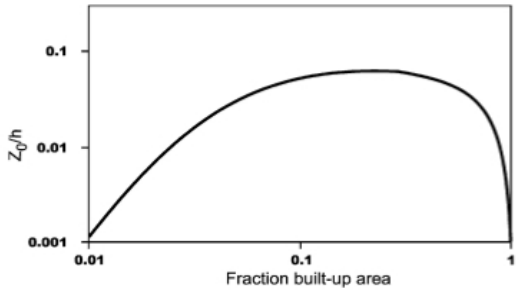

Figure 3.4: Convective Heat Loss
Source: Mills [39]; original: Bottema [40]

Latent Heat: Evapotranspiration $[\lambda E]$

Evapotranspiration is the transfer of moisture from the land to the atmosphere via surface water, plants/trees or soil. It is the combination of both evaporation (water/soil) and transpiration (plants/trees) and has a cooling effect on areas [21], because the process transfers energy from the surface to higher layers of the atmosphere[6] [41]. The transformation of rural to urban landscapes is thus decreasing this opportunity to cool down areas. Bastiaanssen [42] researched the process of evopotranspiration and states that it is a part of the surface energy balance and determined by other factors such as sensible heat $[H]$ or soil circumstances. This shows the incredible degree of complexity of the process, it will therefore not be further examined here.

Ground heat fluxes: Thermal Storage *[G]*

Unlike the other factors, ground heat fluxes have not yet been studied in detail. In general, lower solar reflectance of urban surfaces leads to an increase of thermal storage, which is basically the storage of heat in the ground. However, new studies [21] show that thermal storage is influenced by urban geometry and specific building materials as well. In conclusion, we can only state that the lower reflectance of urban materials lead to more thermal storage and an increase of urban temperatures. Therefore, we will not further investigate thermal storage here.

[4] We will not discuss the exact function of the three factors in this research, for more information see the related references.

[5] The roughness length Z_0/h is a parameter for measuring the horizontal mean wind speed. As the roughness increases, wind speed decrease [40].

[6] The transfer of this kind of heat is called latent heat, which is one of the three determinants on the right side of the UEB [31]

3.3.3 Weather and climate change

It is very important to address the role of weather and climate change and UHI's in a separate section, because there seems to be a much misunderstanding about the relation. Therefore, three comments on this particular subject can me made. First, the geographic location of a city determines obviously a substantial part of the long-term urban temperature. Differences in wind patterns or precipitation due to regional geographic phenomena such as mountains or lakes influence the local climate in a major way [23]. It is therefore important to study the UHI's at the local level, to gain more understanding of the exact situation in a city. Second, local weather influences the daily or weekly temperatures as well. Especially the wind and cloud cover are important, regulating the incoming solar radiation and convective heat loss. As with climatological factors, we need to take local weather into account as well in studying UHI's.

Third, we need to define the roles of climate change and global warming. It is essential that we understand that, as explained before, the UHI phenomenon is defined as increasing temperatures in urban areas *relative to rural areas.* There is therefore not cause-effect relation between climate change and UHI's. With climate change, we usually mean the significant, partly human-induced, changes in our global climate. [24]. It is caused by both natural and human factors, resulting in effects such as sea-level rises, differences in precipitation and wind patterns, air pollution and global temperature changes. The last one is also known as global warming, or the average increase in the temperature of the lowest layer of the atmosphere [21]. It is a part of climate change, together with the other effects. With regard to UHI's, we can thus conclude that UHI's and global warming are two separate phenomena, there is no direct relation between them. However, global warming effects do contribute to UHI's, because they simply result in higher average annual temperatures. On the other side, it would be plausible to say that UHI's contribute to higher global temperatures as well. However, this extra effect is under constant debate, because it is very difficult to measure such a relation. According to Sagan [43] and later Voogt [22], UHI's do not affect global climate change because urban cities only cover 0.25 percent of the Earth's surface. However, other studies show us that the climatological effects of UHI's are a considerable factor in global climate changes. In this research, we will not address this relation any further because the mitigation/adaptation measures and case study both work only on local/regional scale. Instead, we define the role of climate change and especially global warming here as catalyst, contributing to higher average temperatures and thus to the phenomenon of UHI's.

3.4 Impacts of UHI's

The most recognized impacts of UHI's are primarily health-related. Recent heat waves, with thousands of deaths as a result, lead to several national discussions about UHI's and their consequences. However, the impacts on the energy and water sector are recently getting more attention. Since a lot of US cities have been struggling with these issues for several decades, the UHI's lead to new, complex problems that need adequate reactions. Before going to the mitigation and adaptation measures in Chapter 4, this section will first examine the effects of UHI's on cities and their surroundings, starting with increased energy consumption.

Energy

As shown in figure 3.5, when temperatures get higher, people need more cooling to keep them in comfort. Especially large office buildings and residential neighborhoods therefore increase their energy consumption, switching on air-conditionings and other sources of cool air. The increase in energy consumption sets a series of events in motion and is therefore the most important effect of UHI's. Generally, the increase in energy consumption leads to:

1. Pressure on the energy production and energy shortfalls. In the case of Phoenix, the relation between the peak energy demand and temperatures is very clear, as shown in figure 3.5. This puts the energy production and supply under pressure during heat waves, resulting in several energy shortfalls in the US. For example, the California Energy Commission [Miller, [7], p.6] concludes the following:

   > *During the recent July 2006 heat wave .. there was an all time single day record electricity demand of 50.3 GW and several regions within California were without power from hours to days due to infrastructure failures (e.g., transformers in Northern California were unable to cool properly and caught fire).*

   To ensure enough energy supplies for future decades, the energy production of California and other states during warmer periods should thus increase. New technology, improved transmission and distribution will therefore be implemented [7]. However, energy savings are a different way of dealing with this problem. Related to global warming and air pollution, this is one of the major challenges for American cities today. We will discuss this in detail in the next chapter.

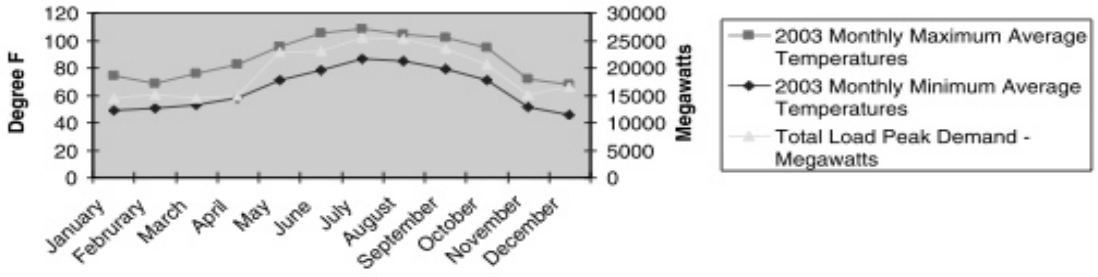

Figure 3.5: Peak electricity demand in Comparison to climate in Phoenix, Arizona
Source: Golden [2]

2. Extra demand and production of energy and more carbon emissions from fossil-fuel combustion [2]. The upcoming section about public health and air quality will discuss this effect.

3. The additional usage of water. The major energy sources of the US still use large amounts of water for the condensing portion of the thermodynamic cycle (Golden, [2], p.17). In his case study on

UHI's in Phoenix, Arizona, Golden [2] estimates that the total water consumption of energy plants in the summer is equal to 74 million gallons per day of groundwater and 26 million gallons per day of surface water, which is about 33 percent of the total water use of the city of Phoenix. As we will discover in this section, water supplies are under pressure during extreme heat, so the extra demand will only intensify the shortage of water.

4. More emission of anthropogenic heat. As mentioned in section 3.3.2, anthropogenic heat is the waste heat produced by increased human activity. More energy consumption leads thus, via primarily air-conditionings, to more anthropogenic heat. Because this is one of the factors contributing to UHI's, a continuous circle forms itself here. Without intervention, this effect will only strengthen the overall effect of UHI's.

Public Heath: Heat Stress

The heat wave in Europe during the summer of 2003 exposed the vulnerability of cities and people in times of extreme heat. Especially in France, where adaptation measures and public information were lacking, the impacts were substantial. In total, the summer caused an estimated 15.000 deaths and even more hospitalizations [44]. In Europe, more then 35.000 people died as a result from the heat wave, which lead to several national and international discussions about heat waves, UHI's and their impacts. Another example of the striking effects of heat waves and UHI's is given by Klinenberg [45]. In his book, he reviews on the heat wave in Chicago in 1995, which caused more then 700 deaths in a couple of days and left residents without electricity for weeks.

The health related impacts of UHI's and heat waves on cities are thus substantial and dangerous. Because the awareness among urban officials and policy makers is often lacking, citizens are not adequately informed and underestimate the danger of heat. In medical terms, a person is in danger if he or she is suffering from *heat stress,* a situation in which the core temperature of the body rises substantially. The symptoms are ranging from heat cramp and rash till life-threatening conditions such as heat stroke [46]. The chance of heat stress is determined by several factors. First, the weather condition has by far the largest impact on public health. As shown in figure 3.6, the US National Weather Forecast uses a chart with several levels of danger regarding heat stress. As we can see, next to air temperatures, the humidity of the air is important as well. This is because in a state of high humidity, the human body cannot emit any sweat to the atmosphere, reducing the ability to cool down. It is therefore important to measure both the variables in times of increased heat. If we compare this chart with actual weather conditions during

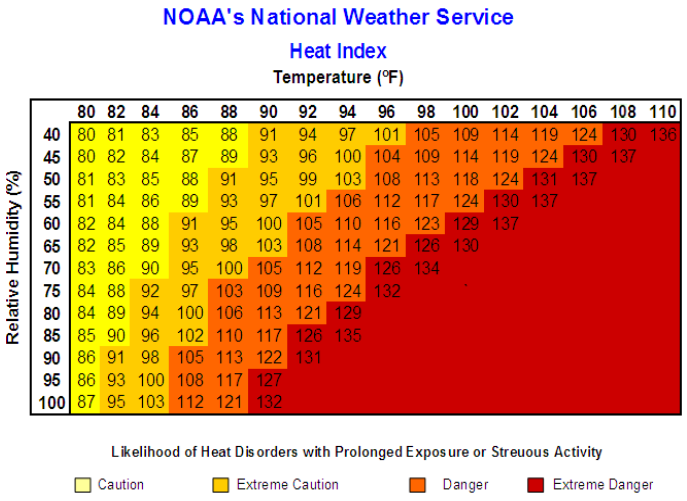

Figure 3.6: Weather and Heat stress
Source: US National Weather Forecast [47]

the summer in some cities in the US, we can conclude that the danger of heat stress is very relevant. The National Weather Forecast defines a heat wave as three consecutive days of more than 90°Fahrenheit and a study from the PEW Center on Climate Change projected [48]:

> *an increase in the average heat wave frequency of about 24 percent for Chicago from 1.7 to 2.1 heat waves per year; 50 percent for Cincinnati from 1.4 to 2.1 heat waves per year; and 36 percent for St. Louis from 1.4 to 1.9 heat waves per year. The average duration of heat waves was projected to increase by 21 percent for Chicago from 7.3 to 8.8 days; by 22 percent for Cincinnati from 8.8 to 10.7 days; and by 38 percent for St. Louis from 10.3 to 14.2 day. (PEW Center on Climate Change, [48], p.7)*

Heat waves and stress are thus threatening the health of urban citizens. In addition, societal and other factors increase the danger of heat stress. For example, especially elderly and socially isolated people, that are not taking care of during heat waves, are more vulnerable then others. The United States Center for Disease Control and Prevention (CDC) published a prevention guide for personal health and safety on their website, regarding these additional factors. In summary, the additional dangerous situations and vulnerable groups are [49]:

1. Elderly people and children without monitoring or control
2. Socially or geographically isolated people without monitoring or control
3. The lack of information and preparation
4. Too little fluid intake, regardless the activity level
5. Rapidly increasing temperatures in cars or other vehicles
6. Outdoor activities without monitoring or control

So, specific groups of people and circumstances contribute to more danger regarding urban heat too. In order to defend themselves against the consequences, people have to become aware of the dangers of heat waves. In terms of heat stress, this is primarily an individual responsibility, influenced by the amount of information a person has access to. In chapter 4, the exact mitigation and adaptation measures regarding the effects mentioned here are discussed.

Public Health: Air Quality

Although UHI impacts on public health are primarily heat stress related, they tend to have a negative effect on the air quality in urban areas as well. As discussed in this section, higher temperatures increase the energy demand of urban areas. The extra demand directly results in more energy production and therewith higher carbon emissions from fossil-fuel combustion; In the US, most of the energy production is still based on fossil fuels which leads to higher emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x) particulate matter (PM) and more [21].
Moreover, higher temperatures tend to influence the occurrence of smog as well. Research from the Heat Island Research Group [50] showed that for every degree Fahrenheit above 70°F. the occurrence of smog increases with 3 percent. Both the previous pollutants and smog have substantial negative effects on the human body, resulting in anything from minor pains to serious respiratory diseases and even long cancer. In Southern California, the relation between UHI's and air quality is studied by Taha [51]. In this study, the mitigation of UHI's is measured in terms of improvements in air quality. So, although the relation between the two factors is studied in the other direction, it gives a good idea of the impact of UHI's on air quality. Figure 3.7 shows the relation between successful mitigation measures and 1) the difference in temperature ($\triangle T$) and 2) changes in the concentration of Ozone in parts per billion ($PPBO3$) for several

cases in Southern California. As shown, as the control in mitigating UHI's increases, urban temperatures and concentrations of Ozone decrease. In other words, successful mitigation of UHI's contributes to improvements in air quality, which is a important statement for the rest of this research.
Furthermore, the air quality problem is highly related to climate change. However, as discussed in the previous section, UHI's are de facto an indirect factor in the larger process of global warming and air pollution. So, it is not true that via the production of smog, UHI's contribute to global air pollution processes. They just work on a local or regional scale. However, it is true that global warming and air pollution threaten the health of urban populations in general and that UHI's are contributing to this because they result in an increase of urban air pollution.

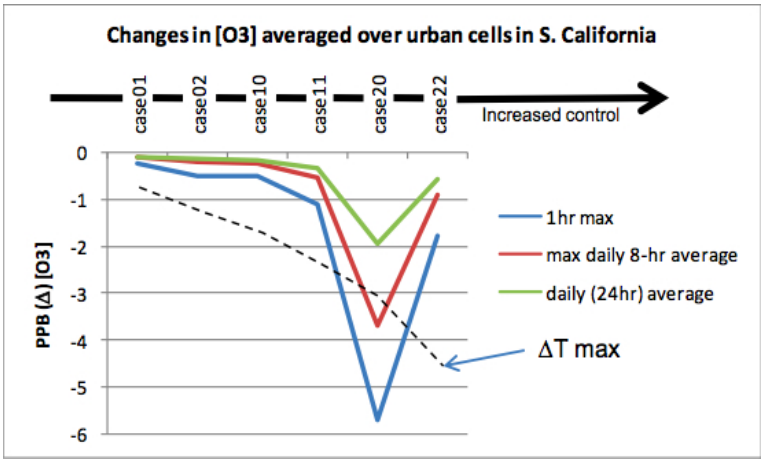

Figure 3.7: Mitigation of UHI's and Air Quality
Source: Taha [51]

Water Resources

It is well known that cities in especially the US struggle with their water quality and supplies. For example, Los Angeles imports almost 90 percent of its water supply from other regions and in other parts of the US the price of water exceeds the price of oil [52]. Case studies of several cities in the Southwest of the US, such as Phoenix, show the importance of understanding the linkages between (urban) climates and water [21]. The role of UHI's in this is important for four reasons: First, the general increase of temperatures effects water resources in the urban area and its surroundings, resulting in more drought and less supplies [2] for the city. This shortage is influencing the public health, business, environmental quality, coastal zones and more. In order to manage the supply and transport of water, the state of California is for example developing a new Waterplan [53], a comprehensive set of policies and measure to ensure water supplies in future decades.
Second, thermal pollution occurs when rainwater reaches urban surfaces such as buildings and pavements. This results in a direct increase of the water temperature, at the time it reaches the sewer the overall increase can be up to 7 degrees Fahrenheit [23]. After transport and deposition in lakes, rivers and streams, the increase in temperature can affect all kinds of aquatic ecosystems life and ecosystems. For example, changes in nutrient cycles or oxygen levels unbalance existing ecosystems and have a negative impact on the biodiversity [24].
Third, the agricultural production, which generally uses 75 percent of the total water supply of a city [52], is highly affected by shortages of clean water. This puts the crops and yields under pressure, with less water the quality and quantity of the agricultural production decreases too. Plans such as the Waterplan should prevent this from happening, ensuring enough water for both urban and rural use.
Fourth, besides the ecological impacts associated with the water quality, increased temperatures effect

the biosphere directly as well. Especially rapid changes in natural environments give natural species and ecosystems not the opportunity to adapt, which leads to weaker ecosystems and loss of biodiversity. In the case of the UHI's, entire ecosystems and species are in danger, due to the substantial rise in temperatures during a certain period.

Economics

All the previous impacts cost a lot of money as well. For example, the extra energy consumption in three US cities alone costs about 26 million dollar per increase of 2-3 °Fahrenheit on an annual basis [54]. Other economic impacts are more difficult to measure, due to the complex structure and formation of UHI's and their effects. However, increased carbon-dioxide and ozone emissions generally lead to more diseases and hospitalizations and thus medical expenses. In addition, in times of extreme heat the productivity and activity of people slows down as well. Especially outdoor labour, e.g. construction and maintenance, suffer from the high temperatures and slow down during heat waves. From the viewpoint of a city, adaptation and mitigation measures are therefore not only necessary, they are very beneficial too.

3.5 Conclusion

In conclusion, the UHI phenomenon has a high degree of complexity, with a lot of separate processes and impacts affecting urban temperatures. Although the first observations are from the 18th century, UHI's have been broadly studied since the discussion on climate change and global warming started in the 1970's. After several decades of substantial research, the exact urban environment in which UHI's occur is now understood. The formation of UHI's can be described in detail too, using for example the Urban Energy Budget. This budget exists of six different factors, all contributing to UHI's and in addition, they influence each other as well which shows the complexity of the issue.

The effects of UHI's are generally well-documented and understood, however, local climatological factors and geography are important in examining UHI's too. It is therefore not possible to develop a general model for UHI's in different locations, the influence of local or regional factors is too large. To develop successful mitigation and adaptation measures, it is for that reason important to investigate UHI's on a small-scale, which is exactly what this research does. Before going to this local occurrence of UHI's, this research first examines the possible mitigation and adaptation measures in the next chapter, in order to develop a framework for the fields of urban planning and design.

Chapter 4

Adapting to Urban Heat Islands

The aims of pure basic science, unlike those of applied science, are neither fast-flowing nor pragmatic. The quick harvest of applied science is the useable process, the medicine, the machine. The shy fruit of pure science is understanding

L.K. Barnett, 1950

Introduction

In the contemporary debate on Urban Heat Islands and their effects, many counter measures are put forward to decrease the negative effects. Many cities such as Montreal [55] have presented plans on UHI's with a broad set of mitigation and adaptation measures. However, the plans, programs and policies differ substantially in terms of the used theory, strategies and implementation processes. It seems that both the theoretical and practical side of adapting to UHI's need to be clarified, in order to develop successful policies in urban planning and design. The question in this chapter is thus which counter measures exist in managing UHI related impacts. In addition, these measures need to be transformed into policies.

To get an understanding of the possible interventions and underlying reasons for using them, this chapter examines the possible mitigation and adaptation measures on UHI's. It starts with a short theoretical introduction about the relation between climate change and UHI management in section 1, before addressing the actual measures in section 2 and the current adaptation policies in the United States in section 3. Furthermore, section 4 will address the role of spatial planning and design in the management of UHI's. This section is important, because it will present us a framework of both the interventions and policies for urban planning and design professionals. This framework forms the basis for the next chapter, because it links both UHI's to interventions and interventions to policies. Finally, this chapter ends with a conclusion, answering the proposed questions in this introduction.

4.1 Theoretical Background

After the first publications in the 1980's on the human side of climate change, scientific explanations and models were presented on the formation and impacts of several phenomena such as the UHI. On the basis of these publications, the first management measures and techniques were developed, which were primarily based on the scientific knowledge of the phenomena. Although the role of humans in climate change became more convincing, the fundamental discussion was still one about the reality and proof [6] of climate change. Therefore, in the first decades, the impacts were seen as environmental problems that needed environmental solutions. This did not change until the late 1990's, when the political and media attention rapidly increased due to a series of natural and social events [56].

The increased attention from society and politics changed the perspective on managing the impacts of climate change. Strategies and measures shifted from a mono-disciplinary perspective with emphasis on the environmental side in order to understand the content of the issue, towards a interdisciplinary perspective with focus on the communication between natural science, policy makers and urban planners

with emphasis on sustainable development [6]. In other words, the approach in managing climate change related effects changed from a more scientific to a social perspective, with focus on communication and interaction between both science and policy/planning.

If we take a look at the way UHI's effects are managed in cities today, we see the social, interactive approach in practice as well. This implies that, in contrast to the scientific basis, the management of UHI's is highly related to climate change issues. The presence of multiple mitigation and/or adaptation strategies confirms this. Mitigation and adaptation are two traditional ways of managing climate change impacts and illustrate the paradigm shift with more practical initiatives. However, in the case of UHI's, there seems to be a substantial variety in the definitions and use of mitigation and adaptation initiatives. There exists a lack of understanding on the difference and similarities between the two approaches; they are often used in the wrong context or chosen without proper motivation. To clarify the distinction between the two approaches, they are separately examined here first.

Mitigation

Historically, managing climate change effects was always based on mitigation, primarily on the reduction of greenhouse gasses. These mitigation strategies are based on scientific disciplines such as environmental science [6]. Typically, they are formulated through institutional arrangements on high geographic scales, the best example of this is the Kyoto Protocol. So, mitigation measures are primarily based on a reduction of greenhouse gasses and therefore reduce global warming on the long term. Or, as defined by the IPCC; *as an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases* [Klein et al. [56] p.553].

Adaptation

In contrast, adaptation strategies were for a long time described as "doing nothing", or "being defeated" [6]. They recently got more attention, when political actors and society started to influence the debate on climate change and demanded more comprehensive actions. Adaptation measures require tailor-made solutions, specific for a certain location or context. The impacts of these measures are usually thus most noticeable locally and work on the short-term [6]. In general, they use a lot of different actors on different scales, all contributing to one adaptation process. In conclusion, adaptation strategies focus on the impacts of climate change and not on the phenomenon itself, they try to find sort-term solutions to reduce the impacts as best as possible. The IPCC defines them *as adjustments in natural or human systems to a new or changing environment* [Klein et al. [56] p.553].

4.2 Overview of Interventions

By introducing some theoretical background, the basis for UHI adaptation/mitigation is provided. According to the research design, the objective of this Chapter is the presentation of some sort of conceptualization of all possible policy interventions in urban planning and design. In order to achieve this conceptualization, a start is made here with an overview of the current possible interventions based on scientific publications in journals.

There are multiple ways for a governmental authority, urban planner, designer or policy maker to adapt to UHI's, the summary of all the interventions is presented in this section. However, not every known intervention is explained, because their practical use and elaboration are not yet developed. This means that only four of the interventions are discussed in detail here; the others fall outside the scope of this chapter. Figure 4.1 provides an overview of all the published interventions regarding UHI's. It is based on a similar overview from [57] and complemented with additional literature sources. Although some of the temperature reductions are not yet clarified, it gives a comprehensive overview of the possible interventions and corresponding effects.

Figure 4.1: Overview of interventions and temperature reductions

Category	**Intervention**	**Effect**	**Max Reduction in (°C)**
Design of Buildings	Use of reflective materials	Decreased radiation absorption	$1.2 - 3.9$
	Cool Roofs	Decreased radiation absorption	$13 - 17$ (surface)
	Green Roofs	Increased evapotranspiration	1.8
		Decreased radiation absorption	$7 - 11$ (surface)
	Thermal Energy Storage	Reducing anthropogenic heat	$2 - 2.5$
	Reducing Energy Use	Reducing anthropogenic heat	1.2
Urban Space	Urban Vegetation	Increased evapotranspiration	$1.5 - 3.1$
	Cool Pavements	Decreased radiation absorption	$1.3 - 3$
	Open and airy spaces	Increased long-wave radiation loss	
	Use of water features	Increased evapotranspiration	$0.7 - 1.3$
	Humidification of surfaces	Decreased radiation absorption	
Urban Geometry	Optimal Shading	Decrease of solar radiation	$9 - 16^*$
	Urban Ventilation	Increased turbulent heat transport	
	H/W Ratio	Increase of Sky View Factor	

$*$ Difference between canopy temperatures in shaded and non-shaded areas [58].

Adapted from: Wong [21], Runhaar et al. [26], Kurn et al. [59], Yoshida et al. [60], Smith [58], Rizwan [57] and Gober [61]

Before linking these mostly engineering interventions to urban planning and design policies, it is necessary to explain the most important interventions in detail. In Chapter 2, the Urban Energy Budget is discussed, an equation that modelled the incoming and outgoing solar energy and radiation in an urban area. This section refers to the budget by addressing the terms from the budget next to the intervention name. This reference shows thus the relation between the budget and real interventions.

1. Urban Forestry [λE]
   The loss of vegetation decreases evapotranspiration processes and therewith the emittance of latent heat. When large scale urbanization patterns occur, this is one of the major contributions to the UHI effect. So, an obvious intervention is the realization of both preservation of existing biomass and the planting of new trees and vegetation. Besides the increase of evapotranspiration, urban

forestry produces significant more shading as well that prevents solar radiation from entering the canopy layer. The US Environmental Protection Agency [21] and Kurn et al. [59] measured that forests can be up to 5°C. [9°F.] cooler than open areas and suburban neighborhoods with trees and vegetation are 2-3°C. [4-6°F.] cooler than similar non-green neighborhoods. Other studies such as Yoshida [60] and Nabeshima [62] also show the cooling effects of vegetation on urban temperatures in international case studies. So, it is not surprising that many cities in the US choose this type of interventions in adapting to UHI's.

2. Cool roofs[*a*]
   The roof is one of the two main objects that influences the urban albedo. As mentioned in the section about the albedo, it effects the balance between reflection and absorption of solar radiation. Darker surfaces tend to absorb more radiation and can heat up to 82 °C. [182°F.] and these surface temperatures influence air temperatures (see Chapter 2). The extensive study from Konopacki et al. [63] addresses the success of cool roofs; it showed that conventional roofs can be 55 to 85 °F. [31-47°C.] hotter than the air on any given day, while cool roofs tend to stay within 10 to 20°F (6-11°C) of the air temperature [63] and [21]. There are roughly three ways of cooling down roofs: 1) with cool roof coatings, 2) with singly-ply membranes and 3) with biomass. The first and second type of cool roofs are thus via special materials that modify the solar radiation budget. The third type are also called *green roofs* and are in fact a combination of cool roofs and more urban vegetation. As Appendix 1 shows, both cool and green roofs have been widely used in the US, especially in large scale projects and residential neighborhoods.

3. Cool pavements [*a*]
   Just as cool roofs, pavements contribute to higher temperatures through the urban energy budget as well. Figure 4.2 shows an example of a street with traditional pavements and the heating effects. Here, the temperature of the pavement is around 140-150°F. (60-65°C.). These traditional pavements store more heat, leading to higher surface and air temperatures. A lot of research has therefore been done on the development of new, cooler pavements, such as permeable pavements. These pavements "allow air, water, and water vapor into the voids of a pavement, keeping the material cool when moist" [Wong, [21], part 3, p.5]. More research on cooling pavements is done by Haselbach [64] and Mallick [65], focusing on the different possibilities to reflect the solar radiations as best as possible. A lot of cities in the US are experimenting with these new pavements, as shown in Appendix 1. These developments are relatively young, because the exact effects of pavements on surface- and air temperatures are not yet clarified. The use of several demonstration projects with different kinds of pavements illustrates this.

Figure 4.2: Temperature of Pavements
Source: National Center of Excellence on SMART Innovations at Arizona State University

4. Green buildings [Q_F]
   The term green building is rather vague, because it covers a broad set of measures, principles, codes and materials all focusing on sustainable buildings. So, not all these interventions are explicitly developed for the adaptation of UHI's, some of them are related to other phenomena. However, all green building activities are managed by the U.S. Green Building Council (USGBC); a non-profit community that encourages the use of green buildings all over the world. The main activity of this community is characterized by the "Leed", which is an international certification system. This certificate helps with the implementation of green buildings in terms of design, construction, operations and maintenance solutions [66] and is shown in figure 4.3. Although the main objective of the green buildings initiative is the mitigation of global climate change through a reduction of greenhouse gas emissions, it is very applicable for UHI's as well.

Figure 4.3: Green Building Certificate
Photo of Leed Certificate in apartment complex in Irvine, CA.

Green Buildings, or sustainable buildings in general, use different techniques to be as energy efficient as possible[1]. In the case of UHI's, they therefore not only decrease the energy demand during heat waves but produce less waste heat as well, resulting in lower urban air temperatures [28]. Moreover, these Green Building principles could be combined with specific UHI counter measures, such as the use of *reflective materials or coatings*. Karlessi [67] addressed the role of energy efficient coatings and found that reflective coatings reflect more solar radiation and decrease the energy consumption of buildings. In general, this means that de total *thermal performance* of the buildings increases, they handle the incoming solar radiation in a more efficient way.
In addition, there are other, more experimental interventions regarding buildings and its nearby environment. On the second International Conference on Counter Measures for Urban Heat Islands in 2009, several studies were presented on this point. For example, the use of *Pedestrian Ventilation Systems* or the use of *Bamboo as Building Material* could be useful in adapting to UHI's. These interventions are in an experimental stage and therefore not further investigated here. However, they do show that the development of UHI interventions is an ongoing process with a lot of different innovative solutions and concepts as a result that might be very useful in future decades.

4.3 Current situation in the US

In order to place this research in a national debate on UHI adaptation and mitigation, this section addresses the current national approaches in managing UHI effects. It presents an overview created by the US Environmental Protection Agency (EPA) [68], which is shown in Appendix 1. It is basically a representation of all the contemporary UHI policies, ordered by state or city. The majority of the initiatives are still based on the Heat Island Reduction Initiative; a federal initiative from the 1990's that

[1]For more information on Green Buildings, visit the website on http://www.epa.gov/greenbuilding/.

bundled all the information on the reduction of UHI's in order to reach out to cities, local communities organizations [17]. The Initiative is replaced by the publication of the Compendium of Strategies; the most recent publication from the EPA regarding UHI's [21].

Although local- or state authorities have to submit the initiatives themselves and control is therefore lacking, it is a good representation of the contemporary measures and strategies used in the US. For example, it shows al kinds of building codes, incentives that promote green roofs or more urban forestry. A critical look of all these initiatives leads to two major observations regarding the UHI responses in the US.

First, there is not a national form of policy on UHI's. The EPA is obviously involved in gathering all these initiatives and publishing them, but their role is limited. Whereas the Heat Island Reduction Initiative had the character of a national program on UHI's, the Compendium of Strategies is not more then a collection of existing strategies and examples. Next to the overview in the Compendium, the national EPA has an indirect role, they support regional and local parties, publish reports on their website and inform society about the effects of UHI's. However, when referring to Chapter 2, the limited role is not surprising since UHI's primarily manifest on a local or regional scales. Possible national regulations or program would therefore not be very effective, since a generalization of the problem of UHI's is almost impossible. In other words, the current advisory role of the EPA is likely to be the most effective in managing the impacts of UHI's.

Second, there are several methods used to initiate a measure regarding UHI's, but the objectives are rather limited. Most of the programs, codes or incentives are aimed at the use of green roofs, cool roofs or cool pavements. There are only a few measures active in the field of zoning, which is a different level of scale in influencing the UHI effect. In other words, the current and completed measures primarily focus on surface- and canopy layers aspects of UHI's. It is thus most likely that there is a discourse among the authorities that these measures give the best results and/or that they are the most cost-effective.
With all the initiatives presented, it is now very interesting to examine what the underlying ideas are behind these initiatives. In other words, referring to the relation between climate change and UHI's, what the approach is US cities us in managing the negative impacts of UHI's. In theory, the current strategies should all be part of the adaptation paradigm; short-term, local initiatives with broad public support and participation. This is because of the fact that global climate change management strategies have shifted towards this perspective and if the relation between climate change management and UHI management is true, UHI strategies should follow the paradigm shift.

Reviewing on the introducing discussion about the theoretical basis of the interventions, a closer look into the US state and cities different programs, incentives and codes shows a broad variety of definitions and objectives, especially considered the adaptation/mitigation paradigm. For example, one city uses "a mitigation program" that should demonstrate the use of permeable pavements in urban environments [68]. This is clearly an example of an adaptation initiative; working on a local scale and short-term. Appendix 1 illustrates that almost all the initiatives have the same characteristics and involve public participation, education and communication as well. So, in theory, almost all the initiatives used by the different US governmental authorities are in fact adaptation measures, they are tailor-made and work on a small scale, whereas the majority is presented as a form of mitigation.

In contrast, indirectly, these initiatives do contribute to a reduction of the emission of greenhouse gasses. So, in that way they could be described as long-term mitigation measures. However, the main objective remains the achievement of short-term results and an overall improvement of the local urban environment.

The city of Montreal in Canada is one of the cases where the theoretical difference is recognized, as the adaptation strategy there is defined as:

> *a change in the way we build and use urban environments to improve the thermal comfort level and reduce serious health risks for residents. This action will have positive effects for the health of residents and decrease summer energy use, among other benefits [Chan et al., [55], p. 67].*

In conclusion, this section overviews the current UHI interventions in the US and places them in the adaptation/mitigation discussion. On the last points, two major observations can be made. First, the management of UHI's did essentially not really shifted towards a different approach in the last decades. It is true that the current approach is based on an adaptation perspective, but the actual initiatives did not changed. It is the way of implementing them that shifted towards a more participatory, communicative approach. This is an important statement for the case study, because it explains the approach and underlying ideas in managing UHI effects today.
Second, although most states and cities use the mitigation perspective, theoretically almost all the initiatives are adaptation measures or strategies. In the rest of this research, adaptation will thus be used in addressing the management approach of UHI's, which means that the interventions are replaced by *adaptation measures*.

4.4 Urban Planning and Design

Up to this point, the focus of the research is on environmental science, climate change, interventions and recently, the adaptation approach. However, while the research falls within a Planning Master, it is now time to examine the planning and design side of the phenomenon. In other words, this section establishes the connection between the possible adaptation measures at one side and the actual planning/design policies and practices at the other. In the Chapter 6, a case study of the city of Los Angeles is presented. The case study shows the occurrence of UHI's in the city and how urban planning and design professionals react to the consequences. In order to examine their activities and resulting policies, this section ends with a framework that shows the possible interventions and policies in Urban Planning and Design.

4.4.1 Towards applied science

The previous sections presented a comprehensive overview of all the possible adaptation measures and explained some of the most important ones. The overview is not more then a collection of information on existing measures, based on a broad selection of articles and reports. The vast majority of the articles is published in climatology, energy and construction journals, as shown in Section 4.2. This is recognized by Mills [39], who places all the adaptation measures and concepts in the realm of the science of urban climatology. In his view, urban climatologists have come up with an accepted framework for investigating and mitigating the effects of UHI's. The understanding of the different layers and processes of urban climates is one of the major contributions to the framework, besides all the different ideas on measuring and influencing the processes and factors that shape the UHI's. However, as Mills states, the understanding of the phenomenon has not yet led to a comprehensive framework of practical, effective counter measures in the field of urban planning and design [39]. In other words, if urban climatology represents the knowledge of the formations and effects of UHI's, the field of applied urban climatology is very underdeveloped.

In his work on localizing global environmental science, Corburn [69] confirms the lack of appropriate knowledge, tools and concepts in dealing with UHI's on the local level. He uses the city of New York as case study to show the inconvenient relation between scientific research, policy development and actual

practices. Regarding this, he presents a concept called the co-production framework; an approach in which both scientists and policy makers work together, based on mutual trust, in order to challenge the difficulty of handling with both the scientific and social side of climate change related issues. An examination of the approach in the case of New York City showed that:

> *the co-production process can produce policy-relevant information. More generally, co-production offers a framework for regulatory science, or science policy that: crosses disciplinary lines; enters into previously unknown investigative territories; requires the deployment of new methods, instruments, protocols and experimental systems; and, involves politically sensitive processes and results.*
> *(Corburn, [69], p.425)*

Although Corburn does not explicitly address the link between UHI adaptation measures and urban planning and design because his focus is on policy making and political processes, it does provide an interesting perspective for this research. This perspective, complemented with the contribution from Mills, formed the basis for the problem definition of this research; the problem of translating the UHI effects into the urban planning and design of a city. Using the background knowledge on the formation and effects of UHI's and its potential measures, this section will now start with the development of several urban planning and design strategies. With regard to the work of Allen and Corburn, the strategies will incorporate both the theoretical difficulties and potential adaptation measures in order to develop a comprehensive idea of the potential roles of urban planning and design in the process of adapting to UHI's.

4.4.2 The adaptation strategy

Although there is lack of a comprehensive view on the role of urban planning and design in adapting to UHI's, there are some guidelines, tools and ideas on this topic available. For example, the work of de Schillens and Evans [70], Hitchcock [71] and Smith [58] all address the issue from an urban design perspective, focusing on one of the issues presented. However, a comprehensive view or framework is thus still missing. To develop such a framework, it is necessary to combine the existing work with the overview of adaptation measures from the previous section, since the majority of the adaptation measures is already related to urban planning and design but developed from a scientific point of view.

The general problem is that a complete implementation of all the presented measures is an utopia; it would require a reconstruction of large parts of the entire city. So, although a specific measure, incentive or program might seem very promising on paper, the question always is how it could perform in an actual environment; it has to function in an urban area that is highly complex, dynamic, valuable and dense. It is therefore that Hitchcock proposed the important *role of change* in his strategy to cool the city of Houston. According to his idea, some parts of the urban environment change more frequently then others [71] and offer thus more opportunity to intervene. For example, roof surfaces need maintenance approximately every ten years and paved surfaces deteriorate even faster, which gives opportunities to replace them with "cooler" materials. In contrary, the vast majority of the built up area accommodates the urban economy and its residents, which leaves almost no opportunity for large scale measures. For urban planning and design it is thus important to focus on the changing part of the city and match them with innovative, tailor-made adaptation strategies. This might seem straightforward and feasible, but the reality is that the UHI phenomenon is very complex and interconnected. Simply changing parts of it is unfortunately not realistic. The formation and effects of UHI's are related to a variety of processes and factors, such as transportation, air quality, energy, climatology and climate change. All these components need to be taken into account before intervening in the urban space.

Moreover, because the fields of spatial planning and urban design differ in their approach to the general issue, they needed to be treated as separate fields in the adaptation strategy. In *the field of urban planning*, adaptation measures need to become institutionalized in a certain process arena; an arena in which participating actors, regulations and actions determine the spatial outcome. If the institutionalizing process succeeds, the measures are implemented in new programs, plans or designs [13]. On the other side, in *the field of urban design*, the process arena is more fuzzy and sometimes not even there; actors, regulations and actions are not defined and the implementation process is less controlled. New measures, often design guidelines or trends, need to become a standard in new designs [58]. Moreover, other factors, such as construction standards, financial commitment and the public opinion, influence this process as well. Any implementations of adaptation measures will thus most likely appear in single projects or design trends [37]. Another distinction between the two fields is the subject of study: where urban planning is always related to a spatial component, urban design pays more attention to the urban form and built environment. This distinction has its effects on the way the two fields can implement counter measures, which will be discussed in the next section. So, although planning and design both face the same challenge, two different approaches are needed.

The Planning Side

Spatial planning in the US is primarily an activity of zoning. The main goal of zoning is the protection of the livability of communities by setting up different, separated purposes for land use (e.g. residential, recreation, retail) [72]. In theory, this would mean that UHI policies need to be implemented in several different land uses, which automatically lead to scattered, non-coordinated policies and practices. To overcome this fragmentation, urban planning is traditionally done in the realm of growth management.

Since the 1960's, the field of urban planning has been dominated by the idea of *Growth Management*; a planning perspective that aims at protecting environmental quality and resources. In the last decades, the perspective shifted from a singular environmental towards a more comprehensive approach; incorporating other issues such as the housing or ecological problems. The shift seemed promising from a UHI perspective; it addresses broader environmental issues and does not focus on zoning policies alone. However, Growth Management policies do not counteract UHI's and might even contribute to the warming effects. It is primarily the concept of compact cities and high-density development that strikes with the adaptation to UHI's. As explained in Chapter 3, high-density urban developments and compact cities negatively influence the UHI effect. Therefore, UHI adaptation cannot be aligned with, or become a part of these policy efforts. So, the environmental problems stands alone in the field of urban planning; adaptation measures cannot be implemented using contemporary planning approaches.

Without a useful general planning approach to follow, the question is thus how single adaptation measures can be transformed into effective urban planning policies. The US Environmental Protection Agency published an overview of the potential human activities in their Compendium on Urban Heat Islands [21]. In comparison to the adaptation measures this is already a step forward because the activities are "applied"; they are not a scientific examination of UHI counteracts but draw upon human action, efforts and activity. The combination of these activities and the change perspective of Hitchcock leads thus to a collection of strategies that are: 1) scientifically reliable, 2) applied for social fields and 3) effective, because they focus on the changing parts of the city. With this insight, specific urban planning adaptation measures can be defined, based on the Compendium and shown in Figure 4.4:

Figure 4.4: Urban Planning Strategies

Intervention	**Adaptation Strategy**
General	Zoning Codes
	Comprehensive Plans
	Outreach and Education
Urban Vegetation	Urban Forestry Programs
	Tree and Landscape Ordinances
	Incentive Programs
	Awards and Certificates
Cool Pavements	Demonstration Projects
	Incentive Programs
	Awards and Certificates
Humidification of Surfaces	Demonstration Projects
	Incentive Programs
	Awards and Certificates
Open and Airy Spaces, Water Features	Landscape Ordinances

The Process Arena

With the potential adaptation strategies defined, the next step is implementing them. Every potential strategy needs to become institutionalized in its own environment; it has to become the new standard for involved stakeholders. However, a long list of possible adaptation strategies is very hard to analyze, some sort of structure or ordering is needed to analyze the institutionalization process. To do so, this research uses the concept of the process arena as ordering feature. It helps to structure the previous strategies and assign them to a certain level of scale. Looking forward to the conceptual framework and case study later, the process arena divides the field of urban planning in several layers. This makes it not only easier to analyze the policies and practices in urban planning, it structures the achieved information in the case study as well.

A process arena is a way of presenting important regulations and stakeholders, therewith it identifies potential conflicts, relations and solutions in the implementation process. It is thus a way of thinking about implementing strategies and not a strategy on its own. In other words, the planning arena "accommodates" urban planning adaptation strategies. When completed, it shows the possible strategies that urban planners could use. The Dutch Ministry of Traffic and Public Works developed the framework in 1998 [73]. In the original form, it consists of three different levels of scale (national, state/province, local), each with its own planning arena (see Figure 4.5).

Figure 4.5: The Process Arena

Urban Heat Islands	Stakeholders	Strategies	Measures
National Level			
State Level			
Local Level			

The levels of scale are the same as this research used in section 4.2, which means the adaptation of UHI's in urban planning can be divided in three levels as well. However, as section 4.2 showed, the national level does not actively intervene in UHI effects and will thus not be taken into account here. To complete the process arena, besides the adaptation strategies from Figure 4.4, the relevant regulations and involved stakeholders need to be identified as well. The overview presented in section 4.2 already

gave some information on that point. Moreover, Hamin [74] and Hitchcock [71] provide more information of the planning context of UHI's, which leads to the complete process arena (see Figure 4.6):

Figure 4.6: UHI Process Arena: Urban Planning

	Stakeholders	Interventions	Regulations
State Level	State Departments Boards and Commissions Research Groups	Incentive Programs Awards and Certificates Outreach and Education	Air Quality Energy Efficiency
Local Level	Municipality Planning Agencies Project Development Local Communities	Comprehensive Plans Zoning Codes Landscape Ordinances Incentive Programs Awards and Certificates Demonstration Projects Outreach and Education	Construction Environmental Public Safety Procedures Resolutions

The process arena exists thus of two levels of scale: the state and local level. On the *state level*, the strategies have a more indirect character. Air quality or energy efficiency problems relate to UHI's, but the management influences urban temperatures indirectly. On the actor side, multiple governmental and non-governmental organizations can be identified. The influence of these actors differs; some are directly involved in the policy making process, others have only a advisory role.
On *the local level*, the influence on UHI's is more direct. The use of comprehensive plans, zoning codes or ordinances directly contributes to the reduction of urban temperatures and are thus very effective. However, the process arena is more complex on this level. Multiple actors, such as local communities or political actors influence the decision process in a major way. Moreover, most of the interventions are subject to specific regulations and permits as well. It is therefore that intervening on this level is a difficult and complex task for urban planners, a challenge that Corburn [69] recognizes. The UHI phenomenon, with its dynamic and interconnected character, adds even more complexity to the process arena, which makes it even harder to plan in an effective way.
The process arena shows an inventory of the possible urban planning strategies in adapting to UHI's. It is a combination of proposed strategies by the Environmental Protection Agency and the concept of the process arena. With specific measures assigned to different levels of scale, the field of urban planning can be easily examined and analyzed later in this research. Moreover, the completed process arena forms the basis for the conceptualization of UHI interventions in urban planning and design.

The Design Side

The essential difference between urban planning and design in the US is the fact that the field of urban design focuses on the built environment, whereas the field of urban planning has a broader scope. The built environment, or settlements that accommodate human activity, is the collection of all the spatial and material products in an urban area [31]. Urban design is thus accommodating human activity in the most efficient way, creating valuable places. The field of urban design has been dominated by the idea of sustainable development in the last decade; an holistic perspective in urban development in which any development today does not harm any further generations in their developments. Although this perspective seems rather vague, the influence is substantial and, in contrary to the field of urban planning, sustainable development does relate to UHI related issues. This section therefore uses the broader concept of sustainable development to analyze the field of urban design and borrows important aspects to conceptualize interventions in useful adaptation strategies.

Campbell [75] discusses the relation between sustainable development and urban design; he uses the triangular approach of 1) economic development; 2) environmental protection and 3) social equity to show the difficulties in implementing sustainable development in everyday practice. A translation of the sustainable development concept into UHI policies would thus result in places that are less affected by heating effects but still ensure economic growth and social equity. In other words, it means that the role of urban design is developing economic valuable, successful urban areas for everybody without harming further generations with heating effects and the known impacts on the environment and public health. However, a transformation of this broader objective into everyday design guidelines or principles is needed here.

Fortunately, several studies tried to solve this problem; Smith [58] , de Schiller and Evans [70] and Knowles [76] all address the issue of sustainable urban design. An important contribution is the fact that de Schiller and Evans [70] separate urban design into three levels; town planning, architectural design and construction details, which are shown in Figure 4.7. Moreover, the studies show that the field of urban design can primarily be influenced by design guidelines. Whereas the field of planning uses measures, policies or strategies, in the field of urban design the design itself is the most important aspect. It is therefore that new design guidelines form the basis for the implementation of new ideas. This separation provides an useful perspective to address the issue of sustainable development and urban

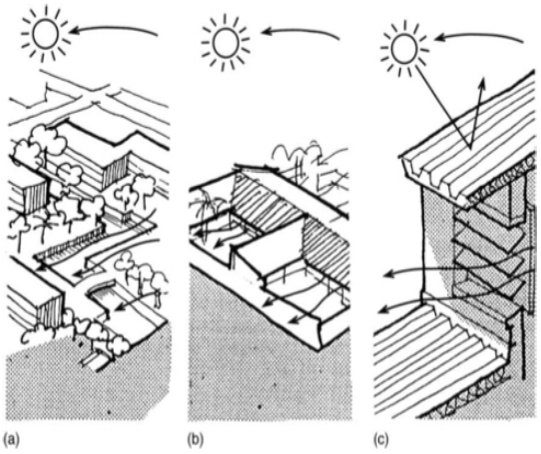

Figure 4.7: Urban Design Scales

Urban design at a) the town planning; b) the architectural and c) the construction scale.
Source: de Schiller and Evans, [70], p.168

design, because it makes it possible to assign specific adaptation guidelines to a certain scale. Moreover, the scales demonstrate a direct link with the separation in urban climates presented in Chapter 2, which strengthens the relation between the scientific and design side of UHI adaptation.

Besides the adaptation measures presented in section 4.2, Smith [58] adds the importance of building regulations and standards for new and existing buildings. The use of energy-efficiency and cooling principles could, according to Smith, deliver improved comfort and more sustainable places in future urban developments [58]. So, the use of building regulations and standards, complemented with the presented adaptation measures leads to a more comprehensive overview of potential adaptation strategies for urban design in adapting to UHI's. Figure 4.8 shows the overview of these strategies, approaching the issue from the three different levels. The overview can serve as a reference for urban design professionals in their challenge to adapt to UHI's in a sustainable way, because it provides short-term strategies and

Figure 4.8: Urban Design Strategies

Scale	Intervention	Adaptation Strategy
State or Local	General	Demonstration Projects
		Incentive Programs
		Buildings Codes
		Buildings Standards
		Awards and Certificates
Town Planning	Urban Ventilation	Building form, location and orientation
		Limit building depth
	Increase Sky View Factor	Provision of open space
Architectural Design	Optimal Shading	Provision of balconies and overhangs
		Building form and orientation
	Reduce Energy Use	Consideration of alternative energy sources
		Use of thermal energy storage
		Provision of adequate space between buildings
		Use of natural lightning in buildings
Construction Details	Reflective Materials	Application in design
	Cool Roofs	Application in design
	Green Roofs	Application in design

guidelines that could be implemented directly. Herewith, it conceptualizes the interventions and presents them as adaptation measures, in line with the objective of this chapter. The final section of this chapter overviews the potential strategies for both planning and design and presents them in one conceptual framework that can be used in the case study of this research.

4.4.3 The Conceptual Framework

A conceptual framework presents certain options in taking action regarding an overall problem; the adaptation of UHI's in the fields of urban planning and design. The framework presented in Figure 4.9 is generated out of all the strategies and guidelines, using three categories and different levels of scale. Is it not a desired state of outcome; it would be very unrealistic to assume that a study area implements all the potential strategies because the issue of UHI's is not the only environmental issue cities have to deal with in their planning and design. It is however an overview of what urban planners and designers at different levels of scale could do to improve the reduction of UHI's in their activities, at the local or state wide scale. With the conceptual framework presented, some general remarks on the implementation of adaptation strategies and guidelines can be made. First, general strategies can be implemented by several different actors, on the state or local level. The use of demonstration projects, awards or certificates such as the Green Building Leed has the potential to increase the awareness among policy makers, project developers and the public society regarding UHI effects. This category of strategies seems perhaps demonstrative or less effective, it nevertheless forms the basis for other spatial or design interventions.

Second, the change concept is important for the field of urban planning. A city as planning subject is highly complex, dynamic and accommodates both residents and economic activity. Intervening in this area is thus not easy; it requires a consensus between a substantial amount of different fields and actors. Moreover, it is impossible to change an entire city at once. That is why the focus on the changing parts of the city is helpful; it automatically identifies the parts of the urban area where interventions have the most chance to succeed. Moreover, a planner has more opportunity to form a consensus here since the involved actors are forced to think about new ideas and concepts for the planning subject. Besides

Field	Level	Strategy/Guideline	Applications
General	All	Incentive programs Awards and certificates Demonstration projects Outreach and education	Urban forestry Cool roofs Green buildings Cool pavements
Urban Planning: *Focus on change*	State	Regulations/Standards	Energy efficiency Air quality
	Local	Comprehensive plans Zoning codes Landscape ordinances	Urban vegetation Open and airy spaces Use of water features Cool pavements
Urban Design: *Sustainable Development*	State/Local	Urban (re)development Building codes Buildings standards and regulations	Cool buildings and built environment
	Town Planning	Urban form, orientation and location Provision of open space Limit building depth	Urban ventilation Increase of sky view factor
	Architectural Design	Provision of balconies/overhangs Urban form and orientation Use of alternative energy sources Provision of space between buildings Use of natural lightning in buildings	Optimal shading Reduction of energy use
	Construction Detail	Application of innovative ideas and materials in designs	Reflective materials Cool roofs Green roofs

Figure 4.9: Conceptual Framework

that, urban planners could use the Smart Growth perspective as a way of implementing UHI's strategies as well. The perspective is well known and commonly used, it therefore offers an existing framework to implement new strategies or ideas.

Third, the field of urban design has another perspective that offers opportunities to implement UHI's strategies and guidelines. The holistic idea of sustainable development might be vague and difficult to implement on the short term, it does offer a relevant perspective for urban design on the long term. In other words, urban designers could use the concept of sustainable development to implement UHI design guidelines in their design and convince involved actors at the same time. Moreover, (re)development projects, building codes and building standards can be used to implement UHI strategies at a bigger scale; they could set the new standard in design guidelines. The role of urban designers is thus two folded; the use of UHI guidelines in their own new urban designs at one side and the effort to standardize UHI principles and guidelines in the entire field of study. In this way, both urban planning and design contribute to the adaptation of UHI effects in urban areas in the most effective way.

4.5 Conclusion

This chapter examined the current ways to adapt to UHI's in the field of urban planning and design. It started with identifying the current counter measures and relevant theoretical background, which led to definition of adaptation measures and strategies. Based on an overview of existing adaptation measures in the US and several insights from the field of urban climatology, a conceptual framework is presented. The objective of the framework is not the establishment of a single adaptation strategy; it does only present the most effective adaptation opportunities for urban planners and designers in their own fields. With the application of these basic insights into practical strategies, this chapters connects urban climatology and applied urban climatology. Therewith it is not only a matter of reference for any city in the US regarding the adaptation of UHI's, or in particular Los Angeles, it contributes to the broader discussion of making global environmental science available for local practices as well.

Chapter 5

Methodology

Design is the method of putting form and content together. Design, just as art, has multiple definitions; there is no single definition. Design is so simple, that's why it is so complicated.
P. Rand (1914-1996)

Introduction

The conceptual framework completed the theoretical part of the research; it connects the proposed interventions to single adaptation measures in urban planning and design. The city of Los Angeles has the desire to become a sustainable, green city, the question is however how the city deals with UHI effects in its urban planning and design. In order to investigate this, this chapter presents the next part of the research design: the methodology. It is very important to explain and discuss the methodology in detail, because any given conclusion or recommendation without proper background is worth nothing. We therefore discuss the each part of the case study separately.

5.1 About the method

The methodology used in this research is a qualitative case study; it is a comparison of empirical data to previous developed theory from several fields of study. This particular method is, according to Yin [77] very useful to understand complex phenomena, where the context affects the case, there are many uncontrollable variables, and the case is a real-world situation. This is exactly the situation in Los Angeles; it illustrates the complexity and different kinds of issues that are related to UHI's and spatial planning and urban design. Before explaining the approach in detail, it is necessary to reflect on some general academic characteristics first.

First; the research falls within the *descriptive* approach, although the theoretical part contains some explanatory components. The main purpose of the research is discovering how certain adaptation theory operates in practice, in this case the city of Los Angeles. In other words, the case study describes how the available theory on certain problems is used in reality. A connection with Gephart [78] can be made here; he states that qualitative descriptive research uses an interpretive approach and addresses questions about how social experience is created and given meaning. Thus, in this point of view the underlying question in the research is if and how social actors (planners/designers) use the existing theory to develop an understanding and reaction on a specific problem in their study area.

Second, some remarks considered the methodological background need to be placed. This research operates, according to Portugali [79] in the gap between the two main methodological cultures; the *hard, natural science* culture characterized by reductionism, mathematics and explanation on the one side and the *soft, social theory* culture characterized by expansionism, hermeneutics and understanding on the other [79]. The reason behind the middle-position lies in the nature of the overall problem; it is a human-induced phenomenon in a natural environment. Both natural processes and social actions are important in explaining certain developments, problems or events, which means that neither pure positivist nor

constructivist methods can be applied in the synthesis of the research; it is a mixture of both cultures and accompanying epistemological views.

So, the question now is how to get out of the "the middle of nowhere land", in order to give properly founded conclusions and recommendations later on in this research. The answer lies a new epistemological stance within the constructivist culture which has its origins in systems and information theory and addresses the social and philosophical limitations of rationality in urban design and planning [80]. This stance is called complexity science or theory; a view that emphasize the role of local interactions and relations in urban environments. According to Zamenopoulos [80] and many others, complexity theory focuses on understanding the organizational and social principles that form functions, structures, patterns or entire phenomena in a city. Although this sounds rather theoretical, it does have some important practical implications for the design and planning of a city.

Considered the complexity idea that the city is a product of human organization and interaction, there must me some sort of intentionally behind the creation of it. After all, the city is a complex collection of artificial objects, designed and planned by people. In this matter, questions arises who or what determines the intentional planning or design of the city. From a complexity theory perspective, the answer to this question is the core factor in explaining the occurrence of a certain development or in this case, response to a certain problem. In other words, complexity theory provides a new direction in thinking about the planning and design of an urban area. This leads to the following guiding principles for the case study of this research which support the quest for useful and reliable conclusions/recommendations [80].
In explaining the response to UHI's in the study area;

1. *cities are the product of design and planning activities*
2. *the focus lies on social and organizational behaviour*
3. *individual actions are guided by goals and beliefs*
4. *macro-level structures are created by individual actions*

These principles will guide the case study in its quest for answers to the research question. However, they are not yet a practical guide in the complex design of the case study; some principles do not form an useful guide. In order to structure the case study, three methodological questions are defined based on the principles. These questions stay within Chapter 5 and 6, they are thus additional to the research overview and questions presented in Chapter 1 and do surely not replace the general structure of the research. The questions aim at structuring the data gathering, analyzing and presentation process:

1. **Something is happening on a city level; who is involved in the planning and design practice of the city?**
2. **What is the result of the planning and design activities by the involved parties?**
3. **What are the goals and barriers of the individual actors behind the involved parties that steer the activities?**

With regard to Chapter 1, the questions do relate to the "three P's": Participators, Policies and Practices. They form the basis of the choices made in the data source selection, extraction method, storage and presentation. In other words, they serve as some sort of sub-questions and, in combination with the information from the other chapters, help to formulate an answer to the main research question.

5.2 Data sources

The data sources selection is based on the first sub-question; who is involved in the planning and design practice of the city? Before this investigation can be made, the scope of the research needs to be defined first. As mentioned before, the method is a qualitative case study because of the high degree of complexity, important role of the urban context and multiple natural and human-induced variables. Moreover, the case study is singular; solely the case of the city of Los Angeles is investigated. This choice is based on two important reasons. First, Urban Heat Islands primarily manifest themselves in densely, built-up areas. In Southern California, the research area, the city of Los Angeles is the only urban area that qualifies itself for these conditions. Second, because UHI's are highly complex and have effects in many different policy fields, the singular focus provides opportunity to investigate the situation in detail. Considered the relatively limited amount of effort and time available for this research, a detailed, in-depth analysis of multiple cases would be very difficult and influence the quality of the analysis.

Before going deeper into the data sources, *the underlying ideas and especially the sequence of the selection process* of data sources needs to be explained first. Because of the fact that the research is conducted in an entirely new environment, without any known contacts, the first goal in the data selection process is meeting a few involved actors. These actors can identify the relevant policies for this research. They know where possible UHI adaptation measures can be found and how the current planning and design system in the city works. Moreover, these actors can identify other involved parties and interesting people to interview as well. Many employees and fellow researchers of the University, in particular the School of Social Ecology, have connections all over the city that could be involved in the research. The involved actors that substantially helped but were not specifically interviewed in this research are:

- Professor Scott A. Bollens, School of Social Ecology, University of California, Irvine (UCI)
- Assistant Professor Tim-Allen Bruckner, School of Social Ecology, UCI
- Assistant Professor Douglas Houston, School of Social Ecology, UCI
- Assistant Professor Jasper A. Vrugt, Civil and Environmental Engineering, UCI
- Assistant Professor Amir Agha-Kouchak, Civil and Environmental Engineering, UCI

These actors, mostly professors at the school of Social Ecology, guide the way in finding relevant data sources in urban planning and design policies and practices. In addition, besides this traditional way of connecting to possible interviewees and finding relevant policies, innovative techniques can be successful as well. The use of professional technological/communication networks such as Linkedin is extremely valuable in finding the right person in an organization or institution and will be used too. In essence, a successful execution of this first step in the data selection process will answer the first sub-question from the methodology.

General Introduction

With many useful sources for both relevant policies and interviewees identified, the next step is selecting some of these sources in order to write a general introduction to the case study findings. The reason behind this lies in the fact that is very important to understand to which effects the city is actually responding. What is the current urban climate, how do UHI's occur and what are the relevant impacts are important questions that need to be answered before addressing the responses in urban planning and design. Both public publications and scientific articles are used to compose the general introduction, they are explained in detail here:

- Publications
  Six different publications on the urban climate and occurrence of UHI's in the city are used to introduce the phenomenon in the case study. Most of these sources are found on websites of the involved parties, others were available at the library of the University or personally send. In general, relevant publications are identified with help of the first meetings with professors and employees that introduced some agencies, institutions or organizations. All these parties are involved in the process of capturing and monitoring the climate in Los Angeles, each from its own perspective. The publications are used because of the information they hold about general climatological characteristics of the city; introducing the issue of UHI's in Los Angeles. The reason behind this is that before addressing the adaptation process of UHI's, it is necessary to know what the situation in casu is; to which effects the city needs to adapt. The numerous figures, tables and numbers in the publications serve thus as background for the case study; they show what the normal climate is, how UHI effects occur and what their effects are. Examples of the data types are temperature and heat wave statistics, climatological developments and other numerical data sources. So, solely the quantitative data from these publications is used, they show current developments and climatological circumstances.

- Articles
  In addition to the numerical data sources from the previous publications, the introduction exists of some articles as well. These articles are all published in journals and found on academic internet search engines; they are therefore also added to the reference section in this research. In the introduction of the case study, they have more or less the same objective as the previous publications. However, they serve more as background information on the occurrence and impacts of UHI's in the city. The articles contain broader information about UHI's in the city; about the stories around heat waves, temperature increases and urban climates. In contrary, they do not contain any quantitative or numerical data, only the textual information is used to write a broader and more comprehensive introduction to the effects in the city.

So, the exact sources of these publications and articles are, just as the other literature sources, included in the reference section. These are basically regular literature sources, used in the case study to serve as background for the research findings. In contrary to the other sources, they are thus not "personally" gathered. In this methodological chapter, this introduction falls outside the explanation about the data gathering, storage and presentation methods, it is more an extension of previous literature reviews and therefore separately mentioned here. However, it is an important aspect of the case study since it provides the background for the following two sections, containing the actual case study data.

Urban Planning

The explanation of the case study introduction initiates the next step in the sequence of data source selection; selecting relevant data sources in the fields of urban planning and design. These two data categories are pure qualitative; they describe the UHI response of both urban planning and design in the city. The choice for specific data sources is based on the previous case study guidelines and the information collected from the first few meetings. In addition, the collected information should provide information to answer the second and third proposed sub-questions, therewith addressing both the results and individual actions/goals of the adaptation process. Figure 5.1 shows the selected data sources in the field of urban planning, all explained in detail here.

- Plans/Programs
  Five different plans and programs are found on websites of involved parties in the urban planning field of Los Angeles. These plans or programs are available to the public and inform about the

Figure 5.1: Description of urban planning data

Sector	Purpose	Actor	Data Source
Planning	State level	The California Energy Commission	Climate Adaptation Strategy
		Cool California	Urban Climate Action Plan
	County Level	Department of Regional Planning	County Green Building Program
	Local level	Department of City Planning	General Plan
			Green Building Ordinance
		Department of Public Works	General Strategy
		LA Urban Forestry Division	Publication: Urban sustainable forests
		Million Trees LA	Publication: The Million Tree initiative
		Central City Association of LA	Downtown Development Plan
		David Sargent	Interview
		Todd Gannon	Interview

current developments in the urban planning of the city. Important is that the plans/programs are not specifically used in the research; they only contain elements of UHI adaptation measures and are therefore included in the case study. In other words, this research is not particularly interested in the Green Building Program of the County of Los Angeles, it only wants to know if this program contains any elements of UHI adaptation measures. An enumeration of these measures, including the following ordinances and publications, shows the current state of UHI adaptation in the field of urban planning in the city. As mentioned before; the information from first meetings is used to identify the relevant plans, programs, ordinances and publications; the enumeration in the case study is therewith a reliable representation of the state of the UHI adaptation process.

- Ordinance
  The Green Buildings Ordinance falls within the same category as the previous plans and programs. However, one major difference is the regulative power of the ordinance. Because it is not a plan, program or strategy but a form of regulation, UHI measures in the ordinance can be seen as successfully implemented or successful result. This is important in the analysis, because the question is if many measures in the plans and programs are really implemented and translated into actual practices.

- Publications
  Two similar organizations Los Angeles published several documents on their websites, two of them contain UHI related measures and are thus included in this research. The LA Urban Forestry Division and Million Trees LA publish their plans and achievements on the internet. Because their activities include a lot of UHI related measures, their publications are used in the overview of UHI related urban planning policies in the city. In contrary to the plans and programs, these publications are not official documents; they are published by the organizations and not a official, governmental representation of the current activities in this field.

- Interviews
  Based on the first few meetings, a number of possible interviewees need to be identified. Due to the constraints in time and money, the selection needs to be small, relevant and effective. In the field of urban planning, two important actors are defined and willing to share their ideas, concepts and activities. These are David Sargent, urban planner and head of the Sargent Town Planning and Todd Gannon, an urban planner specialized in the urban environment and landscape. During the interviews, an important aspect is the conceptual framework of Chapter 4. It will be discussed in order to find out if and why (not) the interviewees take UHI effects into account in their work.

Urban Design

Similar to the field of urban planning; the second and third sub-questions need to be answered in the field of urban design as well. Figure 5.2 shows the used data sources in this field, again all explained in this section.

Figure 5.2: Description of urban design data

Sector	Purpose	Actor	Data Source
Design	State/Local	LA Department of Engineering	Green Building Code
			Sustainable Design Implementation Program
	Town planning	LA Urban Design Studio	21st Century City Plan
		Simon Pastucha	Interview
		Terence Young	Interview
	Architectural design	LA Urban Design Studio	Downtown Design Guide
		Simon Pastucha	Interview
		Nicole Bendtner	Interview
	Construction details	Denzil Lee	Interview

- Plans/Programs
  The three presented plans and programs have the same objective as they had in the field of urban planning. Furthermore, they are selected and used in the same way too, using the first contacts from the University. However, they obviously differ because the field is urban design here. Urban design plans and programs contain more detailed information, they address single situations, architectural plans or construction details. For the research, this means that these plans need to be examined with more detail as well. UHI related measures can be hidden in other measures or not specifically named; an extra level of concentration is thus needed here.

- Code
  With regard to the previously addressed ordinance and urban design plans, the Green Building code needs to be examined in detail as well. It might contain several UHI related measures and is relatively powerful because of the official legal nature of the code. In addition, the code is issued by the Los Angeles Department of Engineering; a very important actor in the overall process of UHI adaptation.

- Interviews
  More attention is paid to the urban design professionals, because the first few meetings showed already a lack of governmental interest for the field or urban design. The work of urban designers is thus more important relative to urban planners, because their actions are hardly influenced by general policies, plans or guidelines. For this research, four urban design professionals are selected and willing to share their information. These are Simon Pastucha, head of the Los Angeles Urban Design Studio; Terence Young, individual Urban Designer in the state of California, Nicole Bendtner, urban landscaper/architect and Denzil Lee, architect in the state of California. The combination of the knowledge, actions and goals of these actors should provide a reliable image of the current urban design practices in the city of Los Angeles.

Summary

The different data sources provide the needed information for the case study and entire research, this finalizes the steps in the sequence of the data selection process. It is clear that all the plans, programs, ordinances and publications handle the second proposed sub-question in this chapter; about the results of the planning and design activities. The interviews with the urban planning and design professionals will provide information to answer the last proposed sub-question; about the underlying goals, actions and barriers in the planning and design practice.

5.3 Extraction of data

With the sources of data defined, the next step in the entire case study is the extraction of useful data. Although this may sound easy on paper, it is often a difficult and underestimated step of the case study [81]. The approach used in this research is similar to many other examples, such as Allen [82], which somehow relates to the complexity theory perspective. The basic principle is the idea that both researcher and data source, often an individual or organization, do and cannot understand a problem or development entirely. Especially in fields of urban planning or design, characterized by complex urban problems and a very dynamic context, it is impossible to completely understand all the different aspects of the case at hand. This is the reason that all the involved actors, such as researchers, project developers, politicians or environmental specialists are in a constant search for new information.

The assumption that everybody is constantly searching for information changes the interaction between the researcher and his source of data completely. In a traditional setting, the researcher is searching for useful data and the data source is willing to help the researcher by providing relevant knowledge. The interaction in this setting can be described as "one-way communication". Although this kind of data gathering can be productive in some situations, the researcher is completely dependent on the willingness of the data source for his or her research. In a situation where both the researcher and data source are searching for new information, the dependency of the researcher becomes an interdependency of both actors; a situation with "two-way communication". This results in a common interest of both actors; a very productive data gathering situation. This idea relates to complexity theory because both the researcher and data source benefit from the interaction. In other words, the interaction is a *learning process* for both actors; they interchange information and develop more understanding about the problem or development. In complexity theory, the learning process is one of the most important aspects of a city; it is the process in which several actors combine their information and knowledge to intervene in a successful way.
In practice, this means that Chapter 3 and especially Chapter 4 are important pieces of information for any involved actor. The presentation of the exact formation, effects and impacts of the phenomenon and the adaptation and mitigation measures is very valuable information for anybody in the environmental/urban planning or design field. In addition, since not many publications exist on this particular topic; the chapters of this research are new and innovative. So, this information will be presented to each interviewee, in order to achieve a form of two-way communication and a learning process.

Before ending this section about the data gathering process, one last comment needs to made. The described process has one major disadvantage; the learning process influences the data gathering and analysis substantially. It is important to recognize that, because every actor is in theory not entirely aware of the problem, gathered information is always subjective. Or, any kind of gathered information has its own context; the environment, background and values behind the information influence the knowledge transfer in a major way. The danger behind this lies in the fact that the subjective and comprehensible nature of the achieved knowledge might result in a less convincing conclusion, or a conclusion that is solely contributing to the information about the phenomenon under these circumstances, in this city. Readers, or other scholars, could question the quality of the methodology if these complexity principles are simply defined in this way.

Therefore, any information gathered in this research is always cross-referenced. This means that statements, findings or any kind of gathered information is always checked and compared to other data sources. For example, if a urban design professional stated that the city of Los Angeles has no single UHI related

policy on the town-planning level, the Los Angeles Urban Design Studio or somebody at the University is asked the exact same question. In practice, this means almost every interview is complemented with follow-up questions per e-mail, if the interviewee is willing to answer these questions. A second great benefit of this follow-up is the fact that the interviewees stay connected to the research, they are aware of the developments and will ultimately also get the results. In fact; this is a second way of making sure a form two-way communication and learning process exists.

5.4 Data storage and presentation

The previous sections presented the selection process of the data sources. Two small tables overview the data collection of the fields of both urban planning and design, accompanied by a general introduction. Because of the substantial variety in the data collection, each source is separately explained as well. In the presentation of the case study only references to journal publications will me made, accompanied by quotes from the several interviews. This means that, instead of transcribing every single interview or commenting on every piece of policy, the more general and/or relevant information from every data source is presented. In addition, a list of interviewees will be added as Appendix to serve as extra reference for the case study.
It has to be said that this process of interpreting data and use the information directly in the case study is rather difficult and vulnerable; a degree of subjectivity can not be ignored here. In practice, this means that the proposed principles and questions are an important guide in producing answers to the research question. They do not only represent a desired outcome, but serve as structure for the presentation of the results as well. With these principles and questions guiding the data presentation process, the assumption can be made that the case study is a reliable and representative study of the situation in the city of Los Angeles.

5.5 Data analysis

Chapter 6 presents the research findings; it is a examination of the current state of UHI's in the city of Los Angeles and the responses in urban planning and design. The conceptual framework and proposed sub-question guide this process of analyzing data, it reveals common thoughts, ideas, barriers or structures and therewith provides information to answers the main research question. However, another analysis can me made here as well by *comparing the research findings with the conceptual framework*. Since Chapter 4 presented the possible adaptation measures, the research findings show some sort of performance of the city's adaptation. Additional questions can be asked and answered in this analysis such as: Which possible adaptation measures are implemented and which are not? Are there any common causes behind the implementation of certain categories measures? How important is the size of scale for the implementation process? These questions will be addressed in a separate section and provide additional information for the conclusion in Chapter 7.

5.6 Conclusion

This chapter discussed the methodology of the research. It is one of the most important aspects of the research, because it is impossible to make any kind of conclusions without a clear and reliable methodology. The methodology here can be described as a singular, qualitative case study with several different components. These components are climatological data about the UHI effects and data about urban planning and urban design in the city. Because of the two-folded nature of the UHI problem, it is both natural and human-induced, the case study will be done through a complexity theory perspective.

A set of guiding principles is defined, which connect the complexity theory perspective to the case study of Los Angeles. Using these guidelines, three important sub-questions are proposed that guide the methodology and case study itself. These questions address the "three P's"; Participators, Policies and Practices. The first P represents the data selection; this process is extensively described and explained. After examining the data sources of the introduction, Policies and Practices in detail; the data gathering, storage and presentation processes are discussed. Finally, an extra analysis of the case data is put forward that will be addressed, in addition to the other research findings, in Chapter 6.

Chapter 6

The case of Los Angeles

The city came into being to preserve life, it exists for the good life
Thomas J. Bradley, Mayor of Los Angeles from 1973-1993

Introduction

The city of Los Angeles is the case study where the adaptation in Urban Planning and Design practice is examined. Before starting off, it is useful to return to Chapter 5 for a moment. Chapter 5 presented three important sub-questions that guide the methodology and execution of the research and case study. After Chapter 5, the second and third sub-question remained unanswered: What is the result of the current adaptation to UHI's and what are the goals and barriers from the individual actors that steer this adaptation process? These questions will be answered in this chapter and serve therefore as guide in the examination of current UHI adaptation in Urban Planning and Design.

The chapter starts with an examination of the climatological circumstances, presence of UHI effects and impacts on the city in the first section. It is necessary to do this, because the context of the UHI problem must be identified first. In other words, it is necessary to know to what the city needs to adapt to. According to Chapter 1 and 5, the adaptation process falls apart in policies and practices; two parts that correspond with the previous unanswered sub-questions. This chapter is therefore divided in these two parts; one about the policy results and one about the current practices. These research findings are then compared to the conceptual framework from Chapter 4; this results in an analysis of the current performance of the adaptation possibilities in the city.

With these findings and analysis, all the sub-questions are answered and concluding remarks can be made. As mentioned before, most of the data sources used in this chapter can be found in the construct table and according explanation in Chapter 5, others are listed in the regular references section.

6.1 UHI's in the city of Los Angeles

The city of Los Angeles is with its approximately 4 million inhabitants the second largest city in the United States and world famous for its coast, downtown and surrounding Hollywood. The city expands over almost 500 square miles, it lies between the Pacific Ocean and the San Fernando Valley, which has some implications for its urban climate. Very important is the straightened Los Angeles River, providing most of Los Angeles' drinking water. In general, the climate of the city is subtropical-Mediterranean, which makes it a pleasant but dry place to live with over 3000 hours of sun per year and not more then 400 mm precipitation per year (see figure 6.1).
The climate of the city of Los Angeles falls thus within the subtropical-Mediterranean category. Besides the pleasant weather, this also means temperatures can substantially rise during the summer. In addition, warming trends, as they occur in every urban area all over the world, have played an important role in the climatological development of the city since the beginning of the 20th century. Although these trends have a more global character, and are thus not similar to UHI effects, they do illustrate the increase

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Maximum Temperature (°F)[1]	68	68	70	73	75	78	83	85	83	79	73	68	75
Average Precipitation (inches)[1]	3.62	4.46	2.28	0.75	0.34	0.12	0.01	0	0.07	0.68	0.72	2.53	15.58

Figure 6.1: Climate data of the city of Los Angeles
Source: California Water Agency Association [83]

of urban temperatures, where UHI's are undoubtedly a part of. Figure 6.2 shows these temperature developments in the city of Los Angeles in the 20th century: a clear increase of urban temperatures in especially the maximum temperatures is visible.

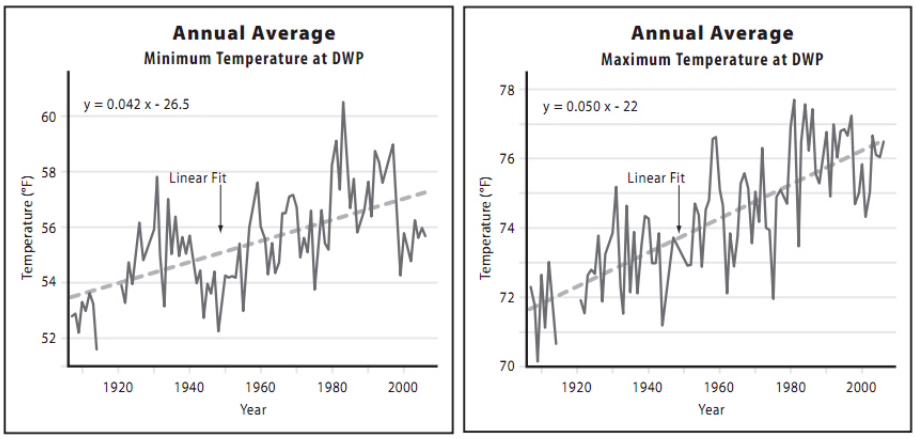

Figure 6.2: Temperature development in the city of Los Angeles
Source: Tamrazian [84]

6.1.1 Occurrence of UHI's

Although the previous warming trends indicate a rise of urban temperatures, they do not, according to Section 2.3.3, proof any kind of occurrence of UHI effects. Robinson et al. [85] does provide the proof for the difference between urban and rural temperatures in Southern California. In his work, Robinson compares over 200 years of temperature data from 2 weather stations; one in downtown LA and one in Fairmont, California, which is a smaller rural town in the surrounding areas of LA. Figure 6.3 shows the differences in the temperatures, with a major increase of urban temperatures in the city of LA, whereas the rural temperatures show no or cyclical warming trends. This means that, besides the more general warming trends, the increase of urban temperatures is substantially higher then comparable rural temperatures; the essence of the UHI definition.

A second conformation is given by Ladochy et al. [86]. Ladochy et al. focus on the annual mean temperature changes in California in the period of 1950-2000. Figure 6.4 shows that urban temperatures have risen in both the cities of San Francisco and Los Angeles. Furthermore, the increase of the temperature is between 0.6 - 0.8 °C per decade, which is a substantial overall rise, especially compared to the non-urban regions. This shows that UHI effects, although our global climates are changing and temperatures increase, do occur in the urban regions and have substantial influence on urban temperatures. In addition, these developments result in a serious increase of the number of heat waves in the city. Figure 6.5 illustrates this increase; Tamrazian shows a significant increase in the 20th century. In his work, a heat wave is defined as a period of three consecutive days above 90°F. (32°C.) The fact that these heat waves have serious impacts on a city is explained by the next section.

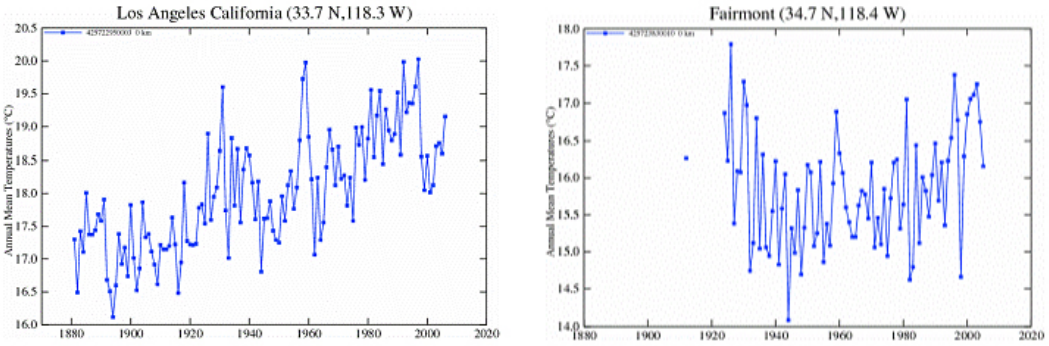

Figure 6.3: Urban vs Rural temperatures in California
Source: Robinson et al. [85]

6.1.2 UHI impacts

An examination of the UHI impacts on the city of Los Angeles leads to a new vision on UHI impacts; although the impacts are similar to previous theoretical findings, the public opinion and general way of thinking behind them are totally different. This new vision can be illustrated by a quote from Assistant Professor Tim-Allen Bruckner (University of California, Department of Public Health, Planning, Policy and Design), who states that:

> *Although Urban Heat Island impacts are very serious, they are, relative to other climatological health impacts such as the flu in the winter, not dangerous for the public. With relatively easy measures, such as effective public instructions, most of the UHI impacts can be controlled in terms of public health problems.*

Other interviewees confirmed these findings, which means that a redefinition of the significance of UHI impacts is necessary. It seems that the significance of the UHI impacts lies in the unsustainable development of a city instead of a human-threatening situation. This statement can be illustrated through three major developments; the increase of energy consumption, decreasing local air quality and water resources.

Energy Consumption

Because of the fact that the national government does not have any kind of UHI related policies or regulations, in terms of energy consumption, the California Energy Commission is the most important actor. In 2007, they published an important document on the relation between extreme heat and energy consumption. They understand that this relation is very strong and discovered a significant correlation between near-surface temperatures and electricity demand during periods of extreme heat, mainly caused by air conditioning devices. Moreover, they state that California's total energy demand is rapidly increasing, driven by the enormous population growth in the state. An important example is the summer of 2006, when both Los Angeles and Sacramento experienced an intense heat wave from more then 10 consecutive days. The heat wave resulted in an all-time record of electricity demand and left several regions without any power for days. During this period, 30 percent of the total energy demand was due to cooling devices in the state.

So, the energy consumption during periods of extreme heat is problematic; the capacity and reliability of the producing system is not sufficient. This temporary scarcity of electricity has already resulted in industries moving to other regions; a development that will become more visible in the next decades. Although the electricity supply is experienced as the major problem in relation to UHI effects, this research examines the other side of the issue. UHI effects lead de facto to higher urban temperatures and thus to an increasing electricity demand, which means that adapting to UHI's is a way of decreasing

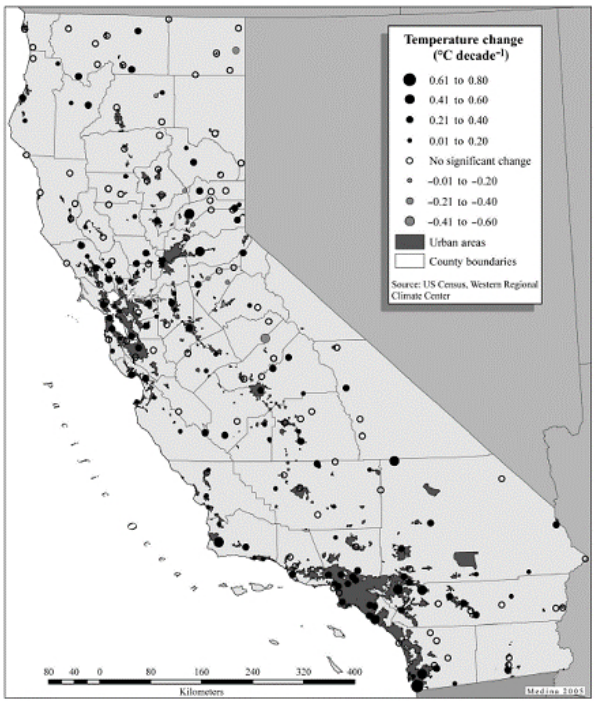

Figure 6.4: Annual temperature changes in California
Source: Ladochy et al. [86]

the electricity demand. In this way, the current and future electricity production would be sufficient or at least secured. Moreover, it is a way of breaking through the ongoing circle in which the use of air conditioning leads to more anthropogenic heat, which leads to higher urban temperatures, which leads to the use of even more air conditioning, etc.

In conclusion, the California Energy Commission states that the current developments in global and local climates will challenge the current-day providers of electricity and questions need to be asked considered the adaptation and mitigation of climate change effects. Although the commission does not handle UHI's separately, they do address the underlying cause of the electricity problems. However, these findings have not yet lead to corresponding actions in policies, principles or any kind of measures on this topic. Al-

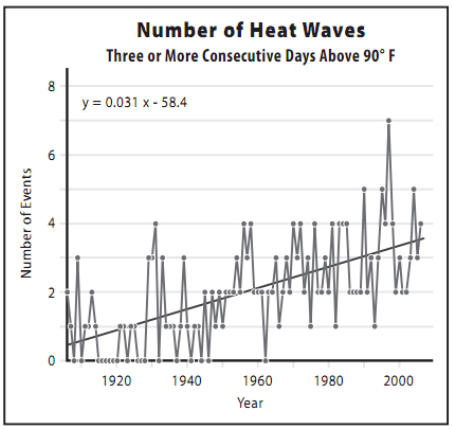

Figure 6.5: Number of heat waves in the city
Source: Tamrazian [84]

though the state of California is very active on the greenhouse gas emission front and published several regulations regarding renewable energy developments and air quality issues, specific attention for the UHI phenomenon or related effects is still lacking. In other words, the state and city only respond to the supply side of the problem; the problem of the increasing demand of electricity is still neglected. Without specific policies, regulations or measures, electricity demands will thus continue to increase in the future and especially during warmer periods, putting the city under pressure.

Air quality

A very early discovery from Cleare [87] in the correlation between urban temperatures and the ozone concentration illustrates the impacts UHI can have on the air quality. Figure 6.6 shows the correlation; as urban temperatures rise; the smog concentration, measured in ozone concentration in part per billion (ppb), rises as well. Ozone is the dominant force in determining air quality standards and therefore the most important variable. In contrary to the electricity issues, air quality problems receive a lot of attention in the city and region of Los Angeles. The California Air Resources Board has developed specific regulations on air quality and greenhouse gas emissions; the AB 32 regulations. Titled as the Global Warming Solutions Act, these regulations pursue a dramatic decrease of greenhouse gas emissions and air pollutants. Since the Act was implemented in 2006 and most of the targets are set for 2020, questions now arise what the exact measures and actions on this topic will be. Cap-and-trade regulations and greenhouse gas emission standards will take effect in 2012, measures that could decrease the current air pollution. An important role in this lies with the South Coast Air Quality Management District, the pollution control agency of the Southern California region. The management district is authorized to use its own regulations, rules and programs to control the air quality in the region and is thus rather powerful in terms of management and control. The implementation of the AB 32 regulations and corresponding actions could help the management district in their battle against the air pollution.

In terms of UHI effects, a direct connection between the AB 32 regulations and the phenomenon does not exist. Where the energy consumption had not any response at all, it seems that air quality issues and UHI effects are managed in a indirect way; through greenhouse gas emissions and air quality standards. The South Coast Air Quality Management District is important here, although the problem of the solely indirect management is the same here. However, the air quality impacts of the UHI effect are in this case thus taken care of, although not from a UHI perspective.

Water Resources

The Los Angeles Department of Power and Water controls, in combination with the California Water Agency Association, the water management in the city. Their activities, guidelines and regulations are presented in the Urban Water Management Plan, a comprehensive plan for all the water issues in the city. This publication, in combination with later results from the interviews, shows that any kind of attention for UHI effects is absent. Considered the data published in the same management plan, the lack of attention for the relation between urban temperatures and water resources is surprising. For example, the plan expects an increase of a little less then 100.000 acre-feet water demand by 2035, which is the same as 123.350.000 m^3 of water, if warming trends continue the coming decades. Besides the fact that this is an enormous amount of extra water supplies, the sources of the current and future supplies is even more worrying.

The city of Los Angeles imports almost 90 percent of its water supplies from other regions or even states. Only 9 percent of the water supplies are extracted from local groundwater, less then 1 percent is recycled. These proportions form a very unsustainable situation themselves; the city is already very dependent on

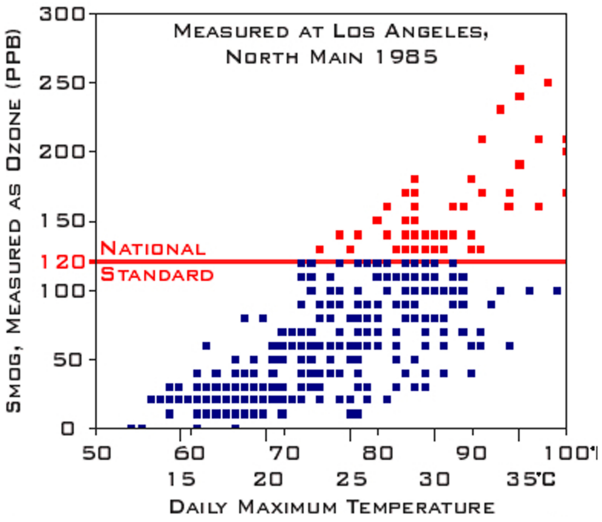

Figure 6.6: Air Quality and UHI effects in the city
Source: Cleare [87]

other regions and this dependency is likely to grow even further in the future. This has implications for the urban economy, livability and environmental quality; the scarcity of water is a very serious problem in the city. It is therefore very important to look further then just the scarcity of water supplies. The role of climate change and UHI related effects in this field is substantial, reasons behind this are presented in section 3.4, but very shortly mentioned in the Urban Water Management Plan.

Although the plan has the objective to manage the impacts of climate change, the only real strategy that can be identified is to reduce greenhouse gas emissions by a proactive attitude towards climate change. Besides the fact that most of the corresponding measures are rather vague, the rationale for taking acting is discussable. It seems that action is needed because the water supplies, and therewith the urban economy, is under pressure and future estimations show an increasing demand. However, from a sustainable point of view, the question arises if it is not the other way around. Is the ongoing economic and population growth simply too pressurizing for the water supplies? This statement requires a different approach; the current straightforward greenhouse gas emission reductions are far from enough. However, this radical shift in water management is in the contemporary development of Los Angeles probably far-fetched; the economic interests are simply too important and population growth will continue to dominate future developments. The lack of serious attention for climate change effects and phenomena such as UHI's will, despite the comprehensive and detailed management plan, probably not guide Los Angeles into a sustainable water resource direction.

The future of UHI's

With the main impacts discovered, a short view into the future underlines the necessity of taking action. The California Energy Commission produced several estimations of Los Angeles temperatures in the future, presented in figure 6.7. The commission identified three different scenarios on basis of global and local climate projections; each scenario shows an increase of days of extreme heat in the city of Los Angeles. It is clear that the UHI effect contributes to these developments and corresponding impacts presented in the previous sections. It is also clear that the human risks seem to be less important; UHI related impacts are parts of a broader unsustainable urban development. The decreasing air quality, scarcity of clean water and increasing electricity demands put the urban area under pressure; action is needed to transform the city into a more livable and sustainable place. The future projections of UHI's

illustrate the necessity behind this, with higher urban temperatures and more heat waves the "good urban life" is in serious danger.

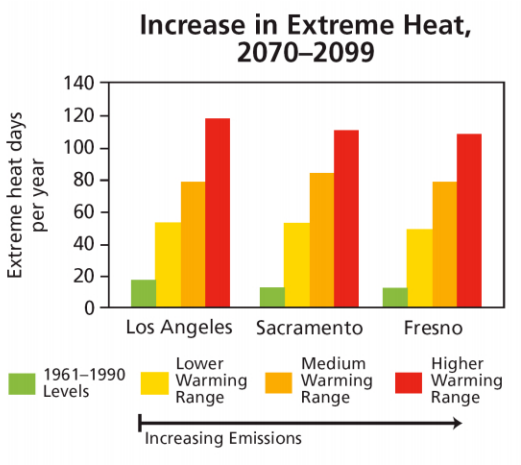

Figure 6.7: Future estimations of Urban Heat in the city
Source: The California Energy Commission [7]

6.2 Policy efforts and results

With the context of the UHI problem defined, this section addresses the UHI adaptation in the policy field of Urban Planning and Design in the city of Los Angeles. This section starts thus with the first unanswered sub-question: *What is the result of the planning activities by the involved parties?* Here, according to the conceptual framework from Chapter 5, difference is made between planning policies on three levels of scale (state-county-local) and design policies on four levels of scale (state/local-town planning-architectural design-construction details).

6.2.1 Urban planning policies

The state level

An important starting point is that the state of California has no state wide planning agency or institution; urban planning falls thus apart in several other agencies, policies or networks. This automatically means that adapting to UHI's is rather difficult; since there exists no form of coordination. However, some activities and developments in the recent years do address UHI issues and try to implement UHI effects in urban planning practices. The policy results of these activities and developments in the contemporary planning practice are:

- The SB 375 Law
  In 2008, governor Arnold Schwarzenegger signed the SB 375; a ground breaking change in land use, housing and environmental law in California. The objective of the law is a reduction of greenhouse gas emissions by discouraging car dependency and sprawl developments. With this objective, the law helps the previous AB 32 regulations by integrating land use, transportation and housing planning. The core part of the law is the "sustainable community strategy", or SCS; a obligation to integrate the AB 32 regulations into new development plans. The SB 375 is a very large step in the good direction because it integrates environmental issues in new regional transportation or development plans. However, the main focus of the law remains on reducing greenhouse gas emissions. It thus a clear example of climate change mitigation. Furthermore, it is plausible that the SB 375 reduces car dependency, leading to less anthropogenic heat production, but no special attention for UHI's exist. The problem of increasing temperatures, resulting in a decrease of air

quality and increase of electricity demand is thus not included in this law. The SB 375 provides major opportunities to incorporate UHI's measures in the fields of land use, regional transportation and environmental law, these opportunities are however not yet utilized.

- Cool California Action Plan
  The cool California Action Plan seems to be promising since it implies a "cooling" strategy. However, less promising is the fact that the Action Plan only deals with global warming effects, which are, as discussed in Chapter 3, different then UHI effects. Several initiatives as the Climate Calculators, carbon footprints, local government calculators and sustainable energy programs are presented here. An enormous variety in carbon dioxide reduction plans and programs is being implemented at the moment; all kinds of institutions and organizations collaborate in a state wide climate change mitigation plan. However, all these policies deal with carbon dioxide emissions and global warming issues instead of paying attention to more regional or local warming effects; attention for UHI's is thus missing here.

- Energy Commission Adaptation Plan
  The California Energy Commission developed a climate change adaptation plan, because according to the plan, "the population, environment and infrastructure are at risk from known future climate change impacts" and "planning and funding do not link with known climate change impacts". Surprisingly, one of the identified threats is urban heat and the plan is called an adaptation plan, so this is could be interesting. First, the plan presents some general objectives, such as "coordination with mitigation plans" and "stimulate interaction and dialogue", followed by specific strategies and efforts. Unfortunately, the attention for UHI's is gone in the last part of the plan; although multiple working groups are defined such as water, infrastructure or biodiversity, UHI or other warming effects receive no specific attention. In this case, the impacts are thus recognized but a specific response is lacking or fragmented among several working groups.

The county level

The county of Los Angeles is a special level of governance between the state and local level. With regard to UHI's, it has one major program that deals with Green Building measures. The program consists of Green Building ordinances and technical specifications for house and small-business owners, both developed to promote the use of green buildings and low-impact developments. In addition, some recommendations are given for land use planning and zoning developments. The Green Building ordinances strive for conservation of water, energy and natural resources and therefore link with the adaptation of UHI impacts. Moreover, they coordinate the work of several organizations, such as "Build it Green", the LEED initiative and many others. Although the UHI effects are not specifically named in these documents, it seems that the objectives, programs and actual ordinances go hand-in-hand with the proposed measures from Chapter 4.

The local level

The urban planning of the city of Los Angeles is done by two departments; the department of City Planning and the department of Public Works. Both of the departments incorporate climate change effects and carbon dioxide emissions in their policies, programs and special zoning plans. Although there exist some attention for UHI's, corresponding adaptation measures do not exist on the local level. Neither of the departments published specific programs, regulations or any kind of policies on UHI's; relevant parts of other policies such as special water zoning requirements are therefore scattered among other fields. Without summarizing all the different tiny parts where existing policies and UHI measures overlap, the conclusion can me made that the city of Los Angeles does not address UHI's as a separate, serious

problem, for one major exception. This exception is urban greening or urban forestry; a sustainable planning initiative in which the city of LA want to become on of the greenest places on the earth.
Basically, the initiative is divided into three separate programs/organizations:

- The Los Angeles Urban Forestry Division (LAUFD)
  The Urban Forestry division is responsible for "the creation and development of street tree policies as well as ensuring the public is aware of these policies and other policies, standards, and guidelines in the urban forest profession". It is thus the legal/administrative representative of the city, equipped with its own policies, standards and guidelines. The overall objective of the division is obviously to become a greener city, resulting in economic, social and environmental benefits. A number of different principles are used, such as the improvement of the tree canopy layer, natural vegetation cover and biodiversity; all reducing UHI effects. It is surprising that the UHI phenomenon is not used a single time in the several publications of the division, since all there activities in fact reduce UHI effects.

- Million Trees LA
  The most important and known activity of the LAUFD program is the Million Tree LA program; a public initiative that strives to plant 1 million trees in the city. Besides the LAUFD, many other actors are involved in this program, it is therefore separately named here. One aspect of the million trees project is especially interesting; the fact that the main objective is to create an extraordinary environment that is able to absorb current and future environmental changes. Again, UHI's are not specifically named, but the connection is very clear. The current tree canopy cover of the city is 21 percent, the objective of the million trees project is to increase this percentage to more then 30 percent.

- The Downtown Development Plan
  Recently, the Los Angeles Downtown Development Plan has been approved and signed. This comprehensive plan serves as a blueprint for the city centre of the city, promoting sustainability initiatives and identifying the key areas of development in the city. The nature of the plan is comprehensive and therefore rather general as well; it needs to be interpreted as a set of guidelines instead of an actual development plan. One of the eleven topics of the plan is open space; an important factor in the adaptation process of UHI's. Whereas the plan promotes the use of open spaces in down town LA; the reality is that 82 percent of the surface of downtown LA is covered with parking lots; all absorbing the radiation from the sun, heating up the city. The question is thus if these guidelines could really make a difference in a extreme car-dependent city, where parking lots dominate the city surface.

Conclusion
A summary of the planning activities on the different administrative levels leads to a conclusion that the planning activities in the field of UHI's are dominated by the reduction on greenhouse gas emissions and several forms of sustainable development. A quest for UHI related policies leads, with two exceptions, to solely indirect connections between UHI adaptation measures and planning policies. Moreover, activities that have an indirect connection are fragmented among different organizations, institutions and administrative scales. This results in a non-structured framework of UHI adaptation policies with primarily indirect linkages between the real causes of UHI effects and existing planning policies.

6.2.2 Urban design policies

Before addressing the urban design policies in the city, it is necessary to comment that there is no policy on the level of the construction details in this field. Some policies exist in the levels of larger scale, but the field of urban design is mostly regulated by other forms of policies such as design/building regulations,

material guidelines etc. None of these categories falls within the field of urban/design or address UHI issues; they are therefore not addressed here.

The state/local level

The Los Angeles Department of Engineering published two documents with UHI related policies and/or measures. These are the Green Building Code and the Sustainable Design Implementation Program. Both documents are available to the public and have the objective to make the city a more sustainable place. Because the Implementation Program is executed by the bureau of Engineering, the main focus of the plan is the greening of buildings. It exists of several policies and ordinances that work together with the LEED imitative in order to promote the use of green building principles. The conservation of energy, use of new technologies and smart use of waste are the leading principles in the Implementation program. Several case studies have been done with the Implementation Program, with success; the public attention have grown and more green developments are planned at the moment.
The Green Building code is a part of the Implementation Program but is, in contrary, legally approved. It is a ordinance that officially obligates new developments to make sure the proposed buildings are more or less green. The code provides regulations for every step of the building process; from construction till maintenance till repair. In general, the regulations of the code are very technical, which automatically means that the scope of the code is limited to the engineering scale of urban design. Although the implementation process and results of the ordinance remain rather vague, it is a substantial step in the right direction since it requires that new developments think about the environment, and therewith about UHI effects.

Town Planning

On the town planning level, the Los Angeles Urban Design Studio published one document that guides and structures all the developments in the city. It is titled "the greening of a century city" and falls apart in five different principles:

1. Create a better pedestrian environment and experience for the Century City
2. Enhance connectivity between pedestrians and transit
3. Create a more beautiful public realm within the Century City
4. Develop an updated identity for what the 21st Century City can be
5. Develop a more sustainable Century City

The third and last principle both incorporate some UHI adaptation measures, although they are not explicitly named that way. The improvement of the quality of the urban area and focus on sustainable development provide opportunity to implement urban greening projects, new reflective technologies, energy-efficient buildings and more open and airy spaces. Although these measures are thus not specifically mentioned in the greening guide, the guide can serve as a general line of thought in which UHI adaptation measures perfectly fit.

Architectural Design

Similar to the town planning level, the level of architectural design exists of only one relevant policy document. The LA Urban Design Studio published the Downtown Design Guide; a guide that promotes a sustainable and green downtown Los Angeles on a smaller scale then the urban greening guide. The focus of the guide lies on the relation between the street and its buildings. The main principles do, again not specifically, adapt to UHI's by addressing issues such as open space, urban vegetation, the use of

sidewalks and more. It works in conjunction with new street standards which emphasize alternatives to the automobile and the use of Green Buildings around them. The most important principle in the light of this research is that in the landscape design, important is the " incorporation of on-site landscape elements that reduces energy use and enhance livability". This is a clear example of a more general UHI adaptation strategy, hopefully results this in specific UHI measures.

Conclusion
Urban design policies exist in a small number in the city of Los Angeles and are mostly a set of principles and guidelines. These guidelines are, except for the urban greening ordinance, not binding, which means that more effort is needed to implement them in the design practice. However, it is not very difficult to spot UHI adaptation measures, although there are not specifically mentioned. The urban greening principles, open and airy spaces and other smaller interventions are used to increase the sustainability and livability of the city and contribute to an UHI adaptation process. Questions however remain if and how these measures are really implemented and why the UHI effect is not treated as a separate phenomenon. The following section addresses these questions and focuses on the planning and design practice of the city.

6.3 UHI practices and individual actions

This final section handles the last unanswered sub-question: *What are the goals and barriers of the individual actors behind the involved parties that steer the activities?* Here, the underlying thoughts, ideas and problems of the individual actors are examined in order to understand why the planning and design exist as they do today. In contrary to the previous, this section has no pre-defined structure; it addresses UHI's from a individual perspective and tries to point out common thoughts, problems or beliefs that steer the urban planning and design activities.

The planning process

The urban planning practice in the US falls apart in two different roles or activities; the development of zoning regulations or ordinances at a level of government and the planning of new, mostly housing, developments. This dichotomy results in a situation where the regular planning activities are thus separated in a regulatory part and a development part; the last one is primarily done by private planning companies, urban planning consultants or hired individuals. Automatically, the parties get a lot responsibility and freedom in planning/executing the developments; since an active role of the government is lacking. This research focused on several urban planning companies and/or consultants in order discover what the urban planning practice in Los Angeles is like, especially considered UHI's.

The planning process of new developments consists of five different stages:

1. Contact with client
2. Development of vision plan
3. Development of implementation documents (plans, guides, ordinances)
4. Development of external documents (gas, sewage, water)
5. Convincing of involved parties

Although these steps form not any kind of official structure, they are applicable in a lot of different developments and planning processes. The first observation that needs to be made is the substantial freedom and responsibility of the planning professional. The management of the development of the

desired project exists of many different aspects; such as the development of strategic vision plans, implementation documents and external documents that serve as guideline for third-parties in the planned area. The last step of the process is perhaps the most important one; convincing involved parties that the desired development must be built, which is in practice a rather political and financial process. All these activities require a substantial amount of knowledge and skill from the urban planning professional.

Knowledge and skill are thus important, especially considered the comprehensive nature of the planning practice. Moreover, the role of the professional or individual is herewith important as well; the individual has the power to determine large scale developments or even certain patterns/structures. This is why it is so extremely important to find out what the underlying goals and beliefs of the planning and design professionals are; they are the key actors in the planning (and UHI adaptation) process.

Design activities

Just as the urban planning practice, the urban design of the city of Los Angeles falls apart in two different roles or activities. On the side, the Los Angeles Urban Design Studio tries to think about the general structures and plans of the urban design of the city. The studio is a separate organization in the Department of Urban Planning and thus responsible for the design guidelines of the entire city. On the other side, small and larger design companies are involved in the design of separate projects in the city. The employees of these companies are a mix of architects and urban designers, these fields mostly overlap.

The Los Angeles Urban Design Studio is an important actor in the development of new guidelines and principles for the city. Surprisingly, the studio has only one or two employees; due to budget constraints the size of the studio is very small. Despite the small size of the studio, it produces comprehensive and detailed documents that are also presented in the previous section. Simon Pastucha, head of the studio, explains that many activities are distributed among other departments, such as the urban planning, public works and water/energy departments. The political attention for urban design is thus not very large; the studio is a small and independent actor in the organization of the city of Los Angeles. It is thus not surprising to see that so little UHI policies exist in the field of urban design.

In contrary to the studio, many different companies and independent urban design specialists work in the city of Los Angeles. An important role here lies with the Los Angeles Urban Design Forum, an open internet-based forum that overviews current and future developments in the city. Moreover, it is a place where the urban design community interacts as well, many stories are told and experiences exchanged. The numerous companies work mostly for new and re-developments, creating urban design at the town planning or architectural scale. It is, considered previous findings, not surprising that the detailed level of construction is done by engineers and other companies.

So, both the Urban Design Studio and several larger and smaller companies do work in the field of urban design, although this has not yet lead to specific policies in the field of UHI's. The question is thus what both urban planning and design professionals think of UHI effects and impacts and if they use specific measures in their daily planning or design practice, since they have the power and ability to change current practices and results in the city.

6.3.1 Individual adaptation of UHI effects

The role of UHI effects and impacts in the contemporary planning and design processes is thus primarily influenced by the ideas, goals and activities of the planning and design professionals. It is impossible to define what all the professionals do with UHI effects in there work, the context, area of expertise and planned objects differ too much for this. However, a number of general observations can me made, all concerning the question how the professionals use UHI effects in their work.

The first observation that can me made is that the adaptation of UHI impacts is primarily a instinctual process, the professionals do use UHI adaptation measures in their work but not from a solid UHI perspective. In other words, they do not always think about the phenomenon and related impacts if they plan or design their objects, even if they are, unconsciously, adapting to it. It thus seems that the professionals do not see UHI's as a serious problem or development, although they do know about the effects and consequences. The major reason behind the ignorance of the effect probably lies in economic pressure that forces their designs and plans to be standard, fast and beneficial. Following sections will address the lack of adaptation in a broader way.

On the other side, as discovered in the previous section, urban greening is one of the major examples of an adaptation strategy in the city of Los Angeles. Both urban planners and designers are aware of the positive characteristics of vegetation and trees, these green elements have been broadly used in new urban developments. However, the livability and aesthetic aspects of urban greening are considered the most important; the adaptation to UHI effects is an additional benefit. Or, as urban designer Terence Young mentioned: "trees and plants are in the designs because they are considered to be nice and beautiful, nobody thinks about there cooling capabilities".

Many urban developments have something to do with residential or commercial buildings. The green building initiative is starting to get more attention here, a very positive UHI development. Buildings become more energy efficient and better isolated, which helps to keep the electricity demands during the summer as low as possible. However, the design of the building is still a problem. "Nine out of ten designers and architects still design what they want the project to look like and hope they will win award and celebrate", as architect Denzil Lee mentioned. For example, reflective materials are considered to be ugly, so there are not used in new designs.

Another observation can me made considered the design concepts regarding site orientation and street patterns. Many of the planners and designers work with these principles, although not always from a UHI perspective. The existing street patterns and design are hard to change and provide no opportunity for UHI adaptation measures, because changing these streets would lead to massive changes in the whole city. In the development of new residential or commercial areas, the orientation of the buildings is still dominated by the position regarding the sun. Although Los Angeles can be very hot during the summer, many clients desire a light and sunny place for the rest of the year.

Finally, the role of the auto mobile is an important aspect of the contemporary developments in urban planning and design. Many of the professionals mentioned that their ideas are shifting from what it seems like efficiency-based plans and designs towards livability-based plans and designs. The use of urban greening principles, use of accessible sidewalks are examples of these new line of thoughts. However, barriers exist in implementing these new principles. The car-dependency is very hard to overcome and efficiency problems arise in street patterns and structures. It seems that, although the professionals are aware of the UHI phenomenon and know what they can do, not many adaptation measures are put

into practice, unless clients ask them specifically to incorporate them in a single plan or design. A shift towards more livability-based plans is happening and provides many opportunities to use more UHI adaptation measures, but professionals struggle with the implementation of these ideas for numerous reasons.

6.3.2 The struggle of UHI adaptation

The interviewees in this research showed a major common goal or driving force: *the development of sustainable communities with less car dependency and more pedestrian friendly environments.* Or, urban planning and design should be in favor of the people living in the city, not the cars driving through it. The sustainable community, a concept that tries to achieve this human-based environment, with renewable energy-resources, less greenhouse gas emissions, pedestrian friendly streets and green urban environments is often used in the urban planning and design practice today. In line with this great idea, Nicole Bendtner introduced the sustainability triangle, a commonly used concept in explaining the aspects of sustainability (shown in figure 6.8). However, in this research, precisely this triangle embodies the first hurdle in the adaptation process and not the desired state of outcome.

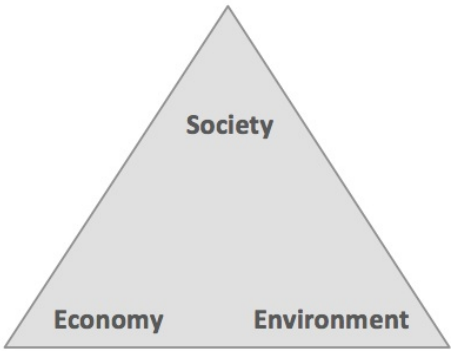

Figure 6.8: The Sustainability Triangle

In the city of Los Angeles, the three aspects of the triangle are not balanced and, in a way, thus not sustainable at all. The last step of the planning process is convincing political and financial parties that the desired development needs to be built; a very difficult, long and complex step. It immediately shows the large role of economic values in the planning practice; new development plans must be economically beneficial at all times for both the developer and involved government. This puts the other values in the second and third place; the importance of societal and environmental values is subordinate to economic benefits. Although this might sound straightforward and well known, it is still the contemporary reality, especially considered UHI effects. Todd Gannon, urban designer, confirmed this by stating "the value of a design is not determined by its beauty or efficiency, it is determined by the current land price."

From an American historic perspective, urban planning and design have always been in favor of development and growth. Industrialization processes and rapid urbanization flows determined the speed and appearance of new developments, with mobility and high living-standards as driving force behind the urban planning and design. Simon Pastucha, head of the Los Angeles Urban Design Studio, compares the residential planning with a

> *building industry that is set up as an industrial assembly line delivering houses in environments that are designed to maximize the efficiency of building and access by automobile.*

It must be said that protecting the environment has always been an objective of urban planning as well, but this is limited to the protection of undeveloped land. The environmental quality of the current urban

areas is less questioned; air quality issues, heat waves and urban drainage have been recently added to the urban agenda.
In the other, societal, corner of the triangle the situation is not much better. Although policies and regulations exist that should separate industries and residential areas, the wrong developments are separated today. Single family housing is separated from multi-family housing, professional offices from corporate offices, all housing from all jobs, and the shops from the residential areas. These separations, together with the inhospitable street networks, have become a machine for making traffic, resulting in problems with the local air quality and even more traffic congestion. The substantial freedom and responsibility makes the urban planners some sort of "urban god"; they use their own concepts and ideas and hope for the best. Too often, their image has no cultural and social credibility, this is illustrated by the many examples of failed redevelopment projects in the region.

The focus on economic growth, development and mobility have prevented UHI's from getting serious attention in the city too. Section 6.1.2 explained that the impacts of UHI are mostly economic and environmental; the decrease or air quality, water resources and increase of electricity consumption result in a very unsustainable urban development. Because economic growth goes hand in hand with more energy and water consumption and more mobility, all impacts are relatively easily refused. In other words, because economic growth seems so to be the major force behind the unsustainable urban development and urbanization processes the major force behind the occurrence of UHI's, serious attention for the impacts of UHI's is lacking.

The second triangle

Moreover, as mentioned before, the UHI phenomenon is highly complex and falls within various fields of study and management. This means that in order to manage UHI effects in a successful way, a level of interdependency between various departments, companies or individuals is required. And it is this interdependency that is absent in the city of Los Angeles; both in the analytical/academic and consultancy/planning world no communication or cooperation exists.
David Sargent, urban planning professional, therefore introduced a second triangle (see figure 6.9) in which the urban planners, designers and engineers are all involved. According to his and other statements, communication between the three professions in the triangle is lacking or very little. The result of this lack of communication is that UHI effects fall between the three professions and the responsibility for sustainable planning and design is divided into specialties that operate in separate "silos". For example, all the decisions related to streets and street networks have been delegated to civil engineers. Without communication, their designs are limited to moving traffic, draining stormwater and traffic efficiency/reducing greenhouse gas emissions. This has led to "urban environments with wide streets full of traffic that are almost impossible to walk around in".
On the other side, urban designers and architects always have the need to express their innovation and creativity. They feel that unless their building stands out as a unique expression of their inner muse they have failed. Without communication with for example planners or engineers, these buildings do not generally contribute to making cities that create human and environmental friendly environments. In general, the lack of communication and working in silos is thus determining the outcomes of current spatial developments. This illustrates the difficulty in adapting to UHI's and explains why UHI adaptation is so fragmented in the city of Los Angeles. UHI's occur in many different parts of the city; involving many different actors and thus little silos. Even if UHI's become a serious and urgent problem in the city, the sum of all the scattered little roles in each silo will not be sufficient to change the urban attitude towards the problem.

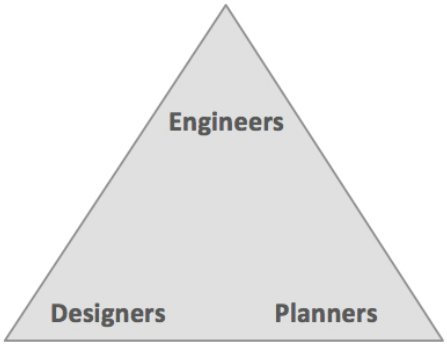

Figure 6.9: Triangle 2

So, the problem of the double triangle explains why UHI measures are not yet implemented in the planning practice. Figure 6.10 shows the problem once again; with the discovered communication barriers in the first triangle and the unbalanced roles of the three aspects in the second. Both triangles prevent UHI measures from implementing into the planning practice of the city of Los Angeles. In addition, they negatively influence each other as well. The lack of communication and dialogue does not change the current approach towards UHI effects, nor does it address important the societal and environmental impacts on a broader level of scale. On the other side, the lack of serious attention for the impacts of UHI's does not stimulate interaction or communication between the three actors in the triangle; the impacts are overshadowed by economic interests and mobility efforts. Both triangles therefore negatively interact with each other, leaving UHI impacts unattached, resulting in a very unsustainable urban development in the city of Los Angeles.

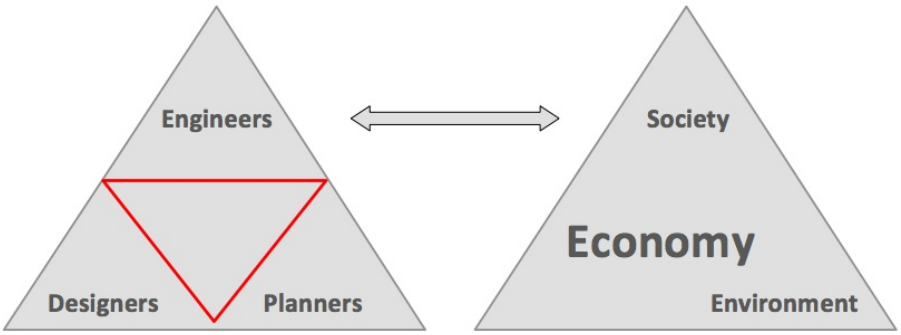

Figure 6.10: The double triangle

6.4 Adaptation and the Conceptual Framework

The general introduction and research findings in the policies and practices of urban planning and design all provide information for the conclusion in the next chapter. Only one piece of information is missing; a comparison of the UHI adaptation process in the city of Los Angeles and the conceptual framework presented in Chapter 4. The conceptual framework presented a range of different adaptation measures divided in different fields and scales; an examination of the previous findings would thus lead to *an adaptation performance* of the city.

The conceptual framework already contributed to the research by structuring the different policies and principles in the urban planning and design of the city, it is now addressed from an evaluation perspective. With regard to all the measures presented, three relevant observations can be made here.

First, on the urban planning state level, regulations and standards on the mentioned topics of energy efficiency and air quality do exist. However, the framework presented these as UHI adaptation measures, whereas the reality shows a different purpose for the regulations. On the local level, the only measure that is implemented is the improvement of the urban vegetation or urban forestry. Although the city uses these measures to improve their sustainable image, they do contribute to the adaptation of UHI effects. Interesting is the general approach presented in the framework, "the focus on change". The implemented measures do not use this concept; UHI measures can be found in the planning of city because some of the aspects of a sustainable urban development contain UHI related problems. The air quality, green buildings and urban vegetation activities illustrate the focus on a livable and sustainable city instead of focusing on changing the city in order to adapt to UHI effects.

Second, it is very surprising that none of the explicit, detailed adaptation measures are used in the field of urban design. Although the city has some urban design plans and programs, they only address general urban vegetation and sustainability ideas. Other measures, such as the building depth, sky view factor, cool roofs and urban ventilation are not yet implemented in any kind of policy. The reason behind this is probably the financial costs and difficulty of using these new features in the urban space. Because many urban design professionals conceive the urban space still as a place for economy and mobility; their design follow the same direction. A direction that leaves little space for new, innovative and sometimes radical changes in the way a city, street or building is designed.

Last, with regard to the research findings, a revision of the conceptual framework is perhaps needed. Whereas this framework uses UHI's as basic problem and direction, the contemporary reality in urban planning and design is different. The case study showed that the focus still lies on the urban economy, mobility and infrastructure, which automatically influences the position of UHI's in the city. A new conceptual framework should, at least in the light of this research, seek for opportunities to implement UHI adaptation measures in the contemporary developments in urban planning and design. Air quality issues, global warming developments or the desire to become a "green city" are for example opportunities for UHI measures. So, the order of the conceptual framework should be the other way around; with a focus on urban planning and design developments, seeking for UHI adaptation measures. This way of managing UHI related effects could perhaps lead to more and better adaptation measures in the city of Los Angeles.

6.5 Conclusion

Adaptation of UHI effects demand a radical change in the way buildings, streets and entire neighbourhoods are planned, designed and lived. It requires the use of new technologies, different building materials, other (mostly low-impact) developments, new street patterns and many other modifications. Some of these adaptation measures already exist in current planning and design policies in the city; mostly in design guidelines and urban greening initiatives. The Downtown Development Guide and Urban Greening Code are examples of this. However, a quick overview of the current policies shows a non-structured framework of UHI adaptation policies with primarily indirect linkages between the real causes of UHI effects and existing policies; activities are fragmented among different departments, companies and other involved parties.

Urban planners and designers are aware of the impacts of UHI's and their planning/design requirements, they have however not the ability, power and will to implement them in there daily practices. The problem of the double triangle explains why UHI adaptation measures are hard to implement. At one side, economic growth seems so to be the major force behind the unsustainable urban development and urbanization processes the major force behind the occurrence of UHI's, serious attention for the impacts of UHI's is therefore lacking. At the other side, the UHI phenomenon is highly complex and falls within various fields of study and management. This means that in order to manage UHI effects in a successful way, a level of interdependency between various departments, companies or individuals is required. And it is this interdependency that is absent in the city of Los Angeles, the adaptation process falls within several different parties.

In addition, both triangles negatively interact with each other, resulting in an extra force stimulating the current indirect management of UHI impacts in the city. An analysis of the possible adaptation measures in Chapter 4 showed that, in the light of this research, the conceptual framework should focus on developments in urban planning and design instead of focusing on UHI adaptation alone. The search for implementation opportunities in contemporary issues such as global warming, urban air quality of urban greening perhaps could lead to more and better adaptation measures. Anyhow, without this change, more communication and coordination, it is likely that not a single new UHI policy is developed, which means that the city of Los Angeles oversees a substantial part of their quest for a sustainable future.

Chapter 7

Conclusion

> *The city is a physical place and includes its citizens; it is above ground, visible, manifest and obdurate.*
> Scott A. Bollens, (in press). Original source: James Hillman, (2006)

The case study ended with a synthesis of the current Urban Heat Island policies and practices in the urban planning and design fields of the city of Los Angeles. Therewith, it answered the proposed questions and provided sufficient information to answer the main research question:

> How is the city of Los Angeles adapting to Urban Heat Islands through urban planning and design?

Before constructing the answer to this question, a short overview of all the chapters of the research is presented. This is important, because each single part of the research is specifically designed and executed to provide as relevant and productive information as possible. Chapter 1 explained the difference between the conclusion and discussion already; it also explained that the broader discussion started in Chapter 2 will not be addressed here.

Chapter 3 started the UHI study with an examination of the exact effects and impacts of the phenomenon. Important aspects of this chapter are the climatological definition, the overview of the formation process and the distinguished five impacts. Based on this, an observation can be made that the UHI phenomenon is an unique case in the field of environmental management, planning and design. It has a high degree of complexity, with a lot of separate processes and impacts affecting the urban environment. Understanding the phenomenon is important, because Chapter 4 followed with possible adaptation measures in urban planning and design. It used several principles to construct a conceptual framework; an overview of all the relevant measures in the field. Herewith, the conceptual framework applied the urban climatology information from Chapter 3 into urban planning and design policies and practices.

The conceptual framework formed the basis for the case study of Los Angeles that covered Chapter 5 and 6. Basically, the main question for the case study was if and how the adaptation measures from the conceptual framework are used in the planning/design policies and practices of the city. Chapter 5 explained the methodology that must lead to the answer to the proposed question. In the light of complexity theory, a single qualitative case study was presented that exists of three important questions. The first question is the who-question and led to the data source selection in Chapter 5. The second what-question and third why-question formed the basis for Chapter 6; the examination of current policies and practices in the city.

All this information now serves as guide and background in order to answer the main research question, an answer that is sharpened by using the exact same phenomenon as metaphor for its management in the city Los Angeles. The adaptation of UHI effects in urban planning and design policies and practices is scattered, non-coordinated, small-sized and therefore not sustainable. Even though many urban planning and design professionals are aware of UHI impacts and feel the need to adapt to them, their activities have

not yet led to sufficient results in planning or design policies. It seems that the adaptation process consists of many tiny urban islands, all focused on other issues and thus indirectly responding to UHI effects.

Urban planning policies do address UHI related problems and adaptation measures, mostly in the realm of greenhouse gas emission reductions and urban sustainable development. In the urban design policies, UHI measures are found in urban greening principles, forms of urban sustainable developments and the even in the governmental search for less car-dependent, more liveable neighborhoods. With regard to the conceptual framework, the urban forestry/vegetation, green buildings and air quality interventions are the commonly used adaptation measures.

However, the quest for UHI related policies solely leads to indirect linkages between the policies and UHI measures, which means that all the policies serve a different objective then searched for in this research. The consultation of multiple urban planning and design professionals makes it clear that these professionals are aware of the serious impacts and feel the need to adapt, they even have their own ideas and points of view about the adaptation process. However, their activities have not yet led to sufficient policy results, mostly caused by two interconnected problems; the problem of the double triangle.

In the first sustainability triangle, economic interests dominate each development in the urban area, the importance of societal and environmental values is subordinate. UHI impacts in the city of Los Angeles are primarily the increase of electricity demands and the decrease of the urban air quality and water resources, impacts that go hand in hand with economic growth. The result is, because economic growth seems so to be the major force behind the unsustainable urban development and urbanization processes the major force behind the occurrence of UHI's, that serious attention for the impacts of UHI's is lacking. The second triangle embodies the problems that occur in the communication between engineers, designers and planners in the city. Because of the fact that the phenomenon is highly complex and divers, the adaptation process falls within different departments, institutions and other involved parties. Where a level of interdependency is needed between all these parties, they currently work in their own silos without communication or coordination. This means that, even if UHI's become a serious and urgent problem in the city, the sum of all the scattered little roles in each silo will currently not be sufficient to successfully adapt to the effects of the phenomenon.

So, the problem of the double triangle explains why the planning and design activities currently result in the scattered, on-coordinated and small-sized adaptation policies and practices. In addition, both triangles negatively interact with each other, resulting in an extra force stimulating the current indirect management of UHI impacts in the city. It seems that, since the value of a plan or design is determined by the resulting land price, and the adaptation process falls apart in many little urban islands, UHI effects do not receive the attention they need if a city wants to develop itself in a sustainable, green way. A short analysis of the presented conceptual framework confirms this; it seems that the focus on UHI's alone does not lead to corresponding adaptation measures. In stead, the conceptual framework should focus on developments in urban planning and design, where issues such as global warming, urban air quality of urban greening provide opportunity to implement more and better UHI adaptation measures. So, without radical changes in the way buildings, streets and entire neighbourhoods are planned, designed and lived, it is likely that the situation will remain the same. Through this way, the city of Los Angeles underestimates a substantial part of their quest for a sustainable future.

Discussion

The city came in danger by the good life, it must exist for the better life

Although the conclusion summarized the current adaptation of UHI effects in the urban planning and design of the city of Los Angeles and answered the research question, the research is not yet finished. This last part addresses broader environmental management issues and tries to extract lessons from the case of UHI's in the city of Los Angeles. Moreover, these lessons can be used as recommendations for the city of Los Angeles in order to get closer to their image of a sustainable future. As explained before, the discussion is based on Chapter 2, with the central part of the research as larger case study.

The hidden structure

Every chapter started with a quote from an involved or famous writer, philosopher or researcher. Besides the fact that these quotes were used to introduce the chapters in a creative way, they have a structural role as well. An aggregation of all the quotes leads to the following enumeration:

Science is organized knowledge. Wisdom is organized life.
Knowing is not enough; we must apply; willing is not enough; we must do.
This town is mere Oven, I feel stifled and roasted.
The aims of pure basic science, unlike those of applied science, are neither fast-flowing nor pragmatic. The quick harvest of applied science is the useable process, the medicine, the machine. The shy fruit of pure science is understanding.
Design is the method of putting form and content together. Design, just as art, has multiple definitions; there is no single definition. Design is so simple, that's why it is so complicated.
The city came into being to preserve life, it exists for the good life.
The city is a physical place and includes its citizens; it is above ground, visible, manifest and obdurate.

These quotes tell us exactly the story behind this research, what it is looking for, in both the smaller and broader sense. The conclusion already addressed the smaller sense, the broader sense is discussed here. According to Chapters 1 and 2, the relevant question here is what the case study of UHI adaptation in the city of Los Angeles tells us about the general problem of transferring environmental and adaptation knowledge into corresponding actions.

The hidden story starts with the statement that science is organized knowledge and wisdom is organized life. This is important, because this research addresses an environmental problem/issue and deals with our cities, places and space. It is impossible to calculate, prescribe and design our environment without thinking about our selves, our own thoughts, ideas and activities. This is confirmed by Goethe, who states that we must apply and do; exactly the idea behind this broader discussion and research. Franklin then introduces the problem, he can literally feel the heat, a problem that is later explained in a natural, climatological way. Understanding the phenomenon is important, but the applied process is the result that is necessary for the case study. The objective of the case study is examining how the applied process is used in policies and practices; the most difficult aspect of the research. The result of the case study is that the examined city has the unstoppable desire to provide the best opportunities to its citizens; they are chasing the "good" life. The conclusion showed that changing the city over one environmental problem is impossible, because it includes its citizens and is above ground, visible, manifest and obdurate.

Analysis

The story represents the general thoughts and ideas of this research and already addresses a few important points that need to be discussed here. Central in the discussion is the fact that almost any environmental problem, including UHI effects, has a multi-disciplinary nature, which means that the causes, effects and impacts affect multiple fields of study and management. The UHI case study shows that, in order to answer the research question, the climatological effects need to be examined first. Understanding how an environmental problem or phenomenon really works is crucial in these types of research; without this information any next step would be useless. The next step was the transferring of the newfound knowledge into basic urban planning and design measures, which was basically never been done before. Moreover, the transformation is the connection between the two fields of urban climatology and applied urban climatology, or pure and applied sciences.

In general, environmental problems always find themselves in the previously called "middle of nowhere land". The interplay between natural processes and human interactions result in a multi-disciplinary degree of complexity, where contextual factors influence the central problem from different directions. The answer to get out of this inconvenient position lies in complexity theory perspectives. New rationales, for example defined by de Roo, state that current environmental problems are so complex and dynamic that, in order to find solutions, the context must determine the management strategy. However, in the case of UHI, the problem is that the context falls apart in many different "silos"; little containers where planning and design policies are developed and brought into practice.

So, what does this tell us about future management of environmental problems in urban planning and design, especially considered UHI's in the city of Los Angeles? The lack of communication and dominating economic interests were identified as major constraints in the UHI adaptation process. These issues occur, exactly as stated by complexity theory ideas, in the context of the overall problem of UHI effects. Some sort of solution lies thus in the context of environmental problems as well.
Based on this research, all the little silos should assemble and try to adjust their activities to each other; this could result in a guided and structured adaptation process. This assembly process is applicable in many different case studies, issues or environmental problems. In many situations, individual activities and thoughts are already adapting to environmental problems, but have not yet sufficient results in policies or regulations. In addition, the "good life" in Los Angeles should be replaced by the "better life" where economic interests and mobility efforts are not taken for granted because of the environmental impacts they cause. This is, obviously, a very difficult and idealistic approach, it might however be the only option if the communication between the involved parties does not improve.

Herewith, the findings from this research fit in the environmental management framework from Eliasson presented in Chapter 2. Two of her key conclusions in the study of the knowledge-action impediment are confirmed here in practice; that an improvement of the awareness for the urban climate and an improvement of communication and argumentation is needed in order to achieve some sort of sustainable urban development. The added principle, stating that the sustainability-umbrella can be used to incorporate single environmental problems in broader policies and regulations, is confirmed with the case study as well. However, in conclusion, all the key conclusions and recommendations have one thing in common; something already addressed in the methodology. The most important, crucial, role in adapting to relatively new environmental problems lies with our selves; with urban planners, designers, engineers, architect, politicians and many other individuals. Their goals, actions and beliefs have the power to create larger structures then themselves, addressing environmental problems and pursuing an (urban) environment that gives anyone opportunity to live the better life.

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Appendix

A: UHI measures in the US

This appendix gives an overview of the interventions made by the US national government, states and cities with more then 600.000 inhabitants [88] to reduce the impacts of urban heat islands. The overview is based on data from the US Environmental Protection Agency [68].

Level	**Area**	**Type**	**Objective**
Nationwide	None	None	None
Statewide	California	Code	Energy efficiency through cool roofs
		Program	Energy efficiency through cool roofs
	Florida	Code	Energy savings through efficiency standards for buildings
		Incentive	Encourage energy conservation
	Georgia	Code	Minimum levels for emittance/reflectance of buildings
	Maryland	Program	Tree planting
		Guidelines	Plan and Design guidelines to reduce urban heat islands
	Pennsylvania	Incentive	Deploy innovative technologies for cool roofs
		Program	Restore tree cover in part of the state
	Texas	Program	Tree plantings throughout the state on public property
	Utah	Program	Promote proper planting and maintenance of trees
Local	Atlanta	Project	Downtown cool pavements
	Austin	Program	Program on green buildings and cool pavements
		Incentive	Policy on building efficiency and cool roofs
	Baltimore	Program	Urban forestry stimulation
	Chicago	Project	Demonstration projects of permeable pavements
		Code	Energy conservation and efficiency through coolf roofs
		Incentive	Program for cool and green roofs
		Research	Estimate impacts from green roofs, encourage installations
		Ordinance	Planting trees on parkways, parking lots and other areas
		Education	Improving urban environments and conserving energy
	Dallas	Program	Cool roofs and green buildings
		Programs	Sustainable skylines-promote urban sustainability
	Detroit	Projects	Cool pavements through demonstration projects
	Houston	Code	Building code for cool roofs and energy efficiency
		Incentive	Stimulation of green roofs, trees and vegetation
		Research	Cool Houston: research on urban heat island in the city
	Los Angeles	Program	Million new trees, urban forestry
	New York	Program	Research and education on green roofs
	Philadelphia	Program	Research on extreme heat in the city
		Program	Cool homes and energy efficiency
	Phoenix	Program	Cool roofs and cool pavements
	San Antonio	Ordinance	Tree preservation and stimulation
	San Jose	Program	green policy for landscape design for heat islands
	Seattle	Ordinance	Sustainable trees and landscapes
		Incentive	Promotion of urban forestry
		Zoning	Minimum green landscape requirements

B: List of Interviewees

The list shows the involved actors that contributed to the research. All the interviews took place in the city of Los Angeles, in the period of April-May 2011.

- David Sargent, head of Sargent Town Planning
- Todd Gannon, Urban Planner
- Simon Pastucha, head of the Los Angeles Urban Design Studio
- Terence Young, Urban Designer
- Nicole Bendtner, Urban Landscaper/Architect
- Denzil Lee, Architect