Visualizing energy flows in urban microclimates

Ties Blaauw
Master thesis
Landscape Architecture and Spatial Planning
Wageningen University & Research

Colophon

Ties Blaauw

Master Thesis Landscape Architecture

Wageningen University

Period:
01.04.16 - 28.11.16

Supervisor:
Dr.ing S.Lenzholzer
Landscape architecture chairgroup

1st examiner:
Prof.dr.ir. A. van den Brink
Landscape architecture chairgroup

2nd examiner:
Dr.ing. S.Stremke
Landscape architecture chairgroup

Landscape architecture chairgroup
Phone: +31 317 484 056
Fax: +31 317 482 166
E-mail: office.lar@wur.nl
www.lar.wur.nl

Postal address
Postbus 47
6700 AA, Wageningen
The Netherlands

1st examiner:
Prof.dr.ir. A. van den Brink
Landscape architecture chairgroup

2nd examiner:
Dr.ing. S.Stremke
Landscape architecture chairgroup

Supervisor:
Dr.ing S.Lenzholzer
Landscape architecture chairgroup

Preface

During my study in landscape architecture I developed an interest in sustainable landscape architecture, in particular climate-responsive design. I was happy to hear that a new course was announced in the Masters programme about climate responsive design and planning. During this course I was able to get acquainted with the basics of (urban) climatology in combination with design. Furthermore I have always been intrigued by visual communication within the discipline of landscape architecture.

Sanda Lenzholzer offered me to study the visualization of energy flows in urban microclimates, which I gladly accepted. With this opportunity I was able to combine my two favourite subjects, climate-responsive design and visual communication. In this research I studied what kind of visualization type could make (urban) energy flows intelligible for urban planners and designers.

During my research numerous persons contributed to the end result. First of all I would like to thank Sanda Lenzholzer for her supervision. You always gave sharp comments and motivated me to keep on going. I would also like to thank the expert group: Gert-Jan Steenenveld, Joao Cortesao, David Huijben, Katarzyna Starzycka, Antonia Cangosz and Gao Zhonglin. We had some interesting feedback sessions and you helped me a lot shaping my research and design. Furthermore I would like to thank all the participants of the survey. You were essential in evaluating the visualizations and came up with helpful improvements. Last but not least, I would like to thank Adri van den Brink and Sven Stremke for their useful comments and feedback upon my green-light presentation.

Abstract

In the next decades (urban) designers and planners will face major challenges concerning urban climate and energy supply. There will be an increase in urban heat caused by human activities and the demand for energy will be ever growing. Climate-responsive planning and design can have beneficial effects on the urban climate by contributing to a reduction of urban heat and helping to reduce the energy demand of buildings and public space. In order to achieve these beneficial effects, an understanding of the characteristics in urban (micro)climates, their thermodynamic system and potentials to generate renewable energy is crucial.

Currently urban planners and designers are not able to comprehend the urban environment in terms of energy flows. They tend to value urban environments as fixed three-dimensional objects and do not consider the manifold dynamic flows present in this environment. The goal of this research was to make urban (renewable) energy flows intelligible for planners and designers, which was achieved by the development of a new visualization method. A thorough literature study on urban climatology, urban renewable energy potentials and visualization, informed the new visualization method. The visualization method was mainly developed by research through designing, which included the planning, data collection, creation and review of the new visualizations.

Animated 3D visualizations, with the use of particle systems, appeared to be the most adequate technique in representing dynamic urban energy flows. A student survey revealed that by using animated 3D visualizations, (urban) planners and designers were able to comprehend the urban environment in terms of (renewable) energy flows. With the new method, (urban) planners and designers will be able to understand the complex interactions of energy in urban environments and how these interactions could benefit the environmental performance of the urban landscape.

Contents

Chapter 1: Research context & framework

1.1 Introduction 1
1.2 Theoretical background 3
1.2.1 Energy flows in urban microclimates 3
1.2.2 Renewable energy flows in urban microclimates 6
1.2.3 Visualization 10
1.3 Towards a new visualization method 17
1.3.1 Research questions 17

Chapter 2: Methods

2.1 Research for- and through designing 19
2.2 Research design 21
2.1 Discussion of methods 27

Chapter 3: Results

3.1 Version 1.0 29
3.1.1 Review of results 35
3.1.2 Improvements 36
3.2 Version 2.0 37

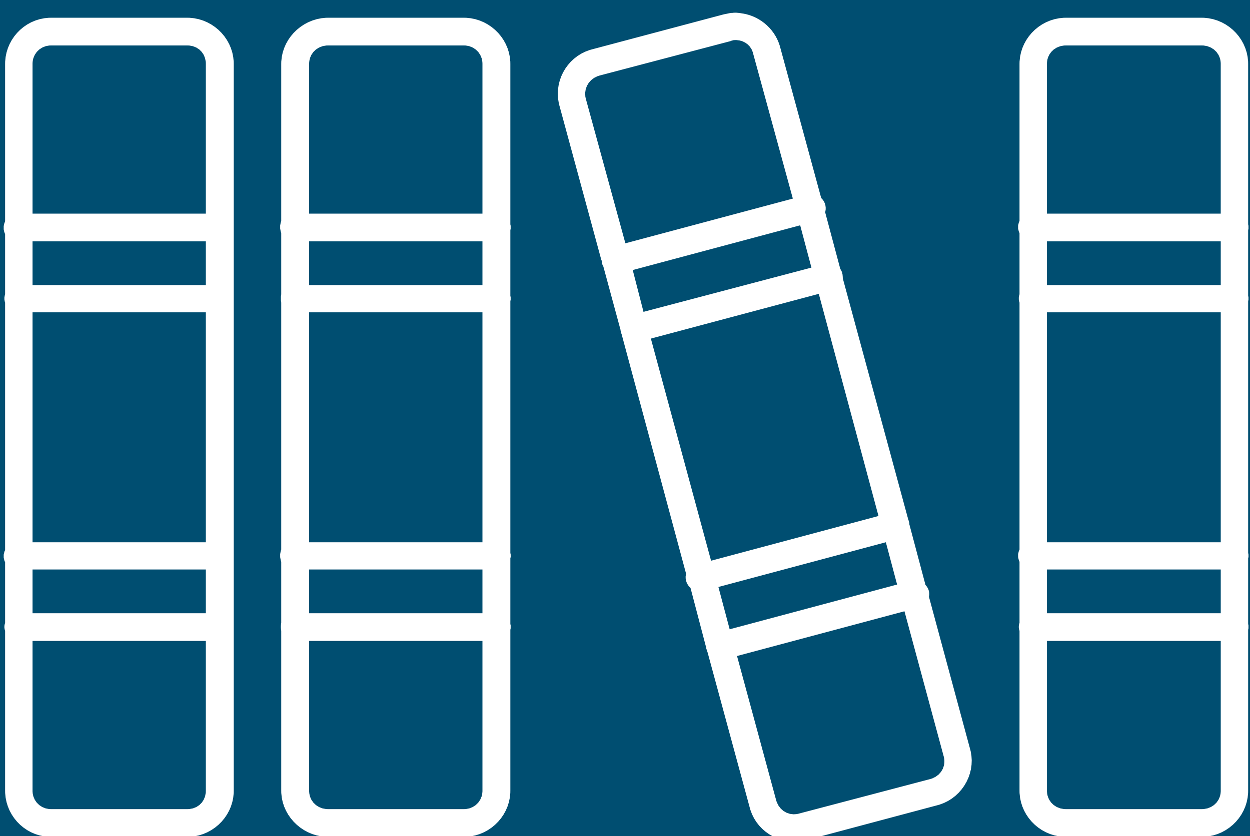
Chapter 4: Discussion

4.1 Discussion 41

Literature 44
List of figures 48
Appendix 50

Chapter 1

RESEARCH CONTEXT AND FRAMEWORK



1.1 Introduction

In the next decades designers and planners will have to face major challenges concerning urban climate and energy supply (Figure 1). Urban microclimates are important thermo-regulators in urban environments. Urban microclimates are small scale climates, which have their own climatological characteristics, such as temperature, humidity and solar irradiation (Vallati et al, 2015). Due to the building density and use of materials, urban microclimates retain more heat from solar radiation than their rural surrounding climate, commonly known as the 'urban heat-island' (Oke, 1982). Effective planning and design can have beneficial effects on the urban climate by contributing to a reduction of the urban heat-island, improving the living environment, and helping to reduce cooling, heating and electricity demand of buildings (Rasheed, 2009). In order to achieve these beneficial effects, an understanding of the characteristics of urban microclimates, their thermodynamic system and potentials to generate renewable energy is essential.

The use of visualization may contribute in understanding the complex interactions of energy flows in urban environments. Humans perceive their environment through their senses. It is estimated that approximately eighty percent of the impression of our surroundings comes from sight (Bruce et al. 1996). Visualizations are able to increase engagement, enhance learning and strengthen people's understanding of complex environmental issues (Sheppard, 2012). Bishop & Lange (2005) identified three major reasons why we use visualization: (1) We visualize to see, experience and understand environmental changes before they occur, (2) through the ability to share this experience and potential for exploration, visualization will help communities to build consensus and make better decisions about their future, and (3) the relationship of people to their environment is a key contributor to environmental decisions, and visualization can help us learn more about that relationship (Bishop & Lange, 2005). So ultimately the use of landscape visualization can contribute to better decisions in urban planning and design. The aim of this research is to make the energy flows in urban microclimates, and the potentials to generate renewable energy, intelligible for planners and designers. This will be achieved through the development of a new visualization method.

Designers and planners are currently not able to comprehend urban environments in terms of flows (Inam, 2013). They tend to value urban environments as fixed three-dimensional objects and do not consider the manifold dynamic flows present in this environment. While this approach leads to visionary thinking and stunning visualizations, it includes an end-point for a phenomenon (e.g. the city), which is actually constantly changing (Inam, 2013). Change involves the fourth dimension, which in urban environments can be conceptualized as flows. Flows represent the process side of the urban landscape.

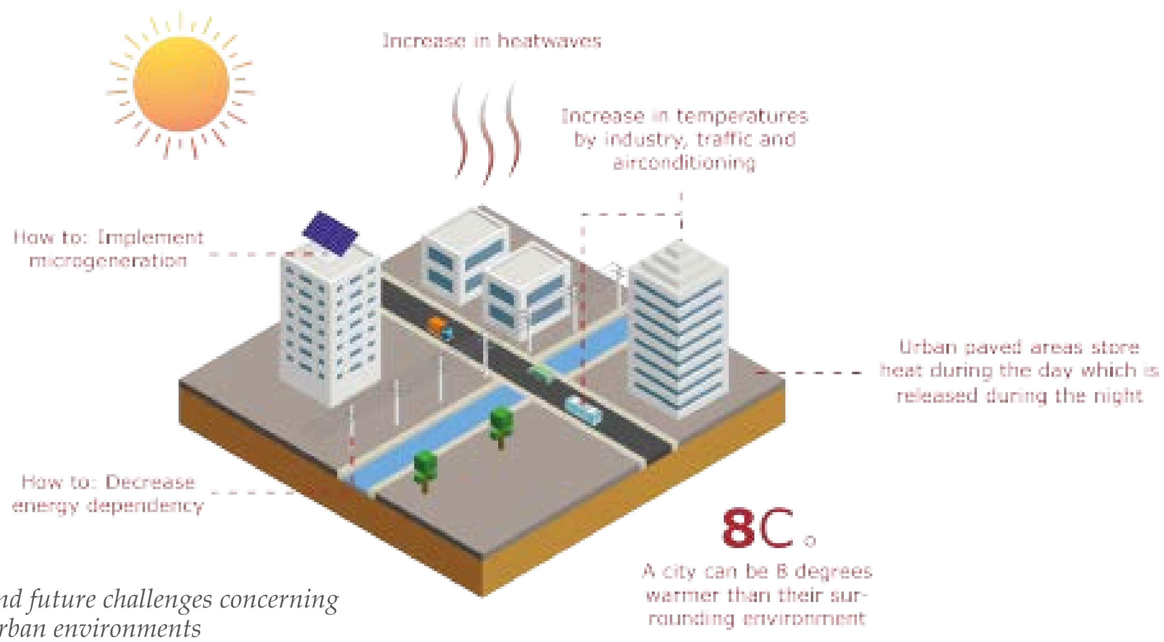


Figure 1: *Current and future challenges concerning heat and energy in urban environments*

By designing cities with flows in mind, the environmental performance of the urban landscape can improve (Brugmans & Strien, 2014). To achieve this, Kennedy et al. (2010) argue that the design community should become much more familiar with energy- and material flows.
To understand energy flows, many energy accounting methods and numerical models are developed by meteorologists, climatologists and other environmental specialists (Allegrini, 2015). Currently there is an abundance of urban energy models to analyse flows on a wide and temporal scale (Keirstead et al. 2012). However, the current models seem to be ineffective for use in planning and design, because planners and designers are not able to comprehend the urban thermodynamic system.

Although many researchers advocate the value of urban climatic knowledge in urban planning and design, they acknowledge that transferring this knowledge into mainstream practice remains a major challenge (Grimmond et al, 2010; Mills et al, 2010; Mills, 2014; Erell et al, 2011; Hebbert & Mackillop, 2013). Part of this problem is the perceived importance of urban climate in (urban) planning and design. When placed alongside other planning issues, urban heat islands have been seen of marginal interest. Another part of the problem is the failure of urban climatology in general to communicate its scientific knowledge into practice in an accessible and applicable manner (Mills, 2014). Urban climatologists have attempted to transfer theoretical knowledge into real-world planning. However, Oke (1984) found a number of shortcomings such as a lack of standardization, generality, transferability, and the absence of clear guidelines which can be adapted by planners and designers (Erell et al, 2011).
To make energy flows intelligible for planners and designers, urban climatic knowledge should be communicated in a clear and structured manner. Overcoming the barriers to knowledge-practice transfer will require accessible knowledge and appropriate communication tools (Mills, 2014). A new visualization method to make energy flows intelligible for planners and designers, could be one of these communication tools.

1.2 Theoretical background

A literature study has been conducted to inform the new visualization method. The literature study elaborates on theories grounded in a variety of research disciplines. An assessment on urban climatology, identified the climatological energy flows, and an assessment on renewable energy, identified the renewable energy flows. Finally, this chapter elaborates on theories within the discipline of visualization, to identify the characteristics of visualization and appropriate visualization techniques to visualize urban energy flows.

1.2.1 Energy flows in urban microclimates

Human settlements and landscapes are part of the physical environment, which is governed by the Laws of Thermodynamics. Thermodynamics is the study of the relationship between heat and work in a system. Energy flows, which consist of radiative- and heat transfer, are thus governed by the laws of thermodynamics. Any attempt to understand how energy exchange takes place at the surface, must start with an analysis of the energy balance (Erell et al, 2011). How the energy flows enter and leave the urban environment greatly depends on local (micro) climate and built-up characteristics. Understanding these interactions can lead to a more efficient and sustainable use of energy flows, for example by generating renewable energy. The concept of the energy balance is derived from the First Law of Thermodynamics. When applied to a simple system, this means that the energy input must equal the sum of the energy output and the difference in energy stored within the system (Erell et al, 2011):

Energy input = Energy output + change in stored energy

However, in more complex and open systems, like cities, the energy in- and outputs are most likely to be unequal. Furthermore, the energy in- and outputs appear in several forms simultaneously and are constantly in imbalance, which will determine if the system is heating up or cooling down (Erell et al, 2011).
The urban energy balance (UEB) influences the microscale effects that control the urban canopy layer (Arnfield, 2003). Microclimates refer to the smallest realm (Figure 2C), where individual structures and trees cast shadows and building materials reflect sunlight (Erell et al, 2011). Microclimates have their own climatological characteristics, such as temperature, humidity and solar irradiation (Vallati et al, 2015).

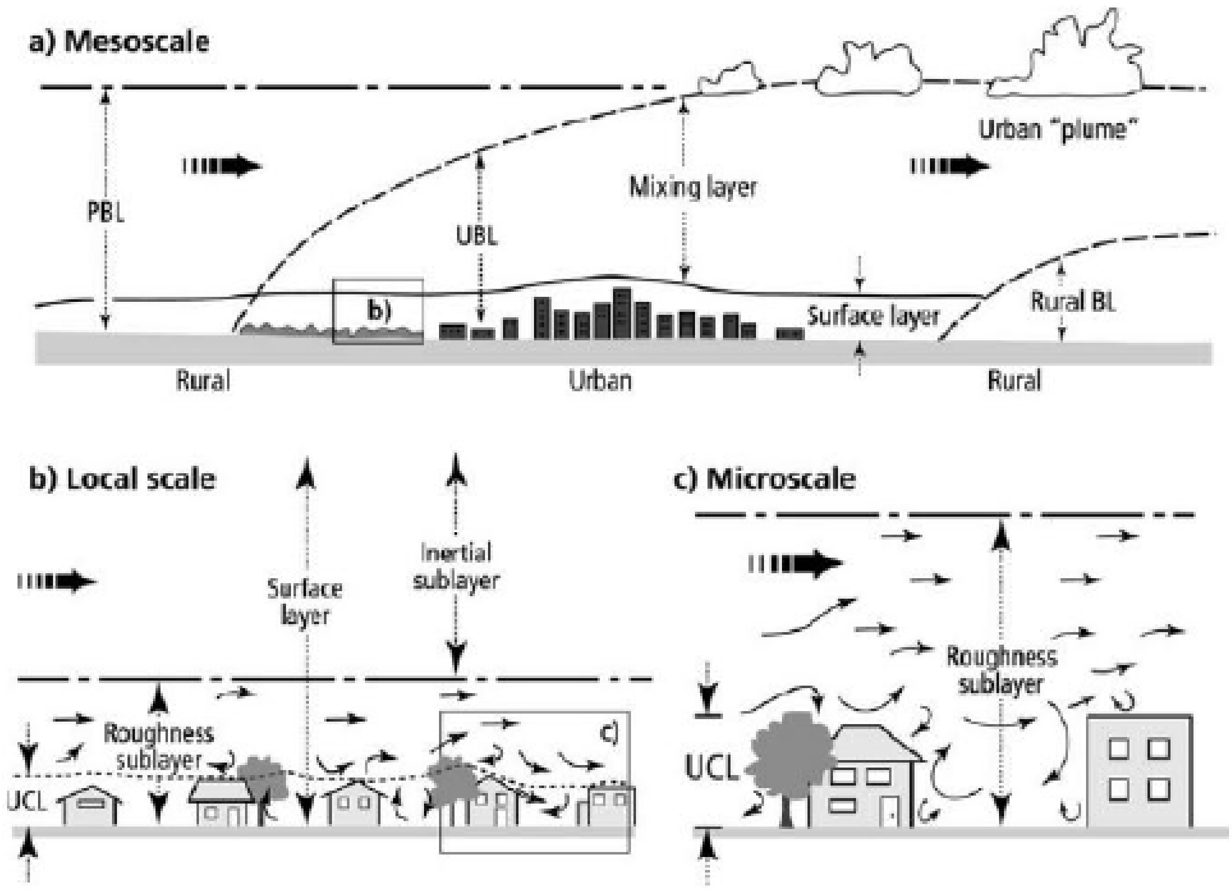


Figure 2: *Scales of the urban climate (Mills, 2014)*

Generally, the UEB is seen as a local- or mesoscale phenomenon, with the built-up area represented as a textured surface that can be characterized by its properties (such as albedo or aerodynamic roughness). Urban energy flows are generally measured above the urban canopy layer to ensure that the measurements represent the overall urban terrain. The UEB equation can be given in watts per square meters:

$$Q^* + QF = QH + QE + QS + QA$$

where Q* is net all-wave radiation, QF is anthropogenic heat, QH and QE are the respective turbulent flows of sensible and latent heat, and QS is the net change in heat storage within the buildings, air, and ground down to a level where heat exchanges become negligible (Pearlmutter & Berliner, 2004).
Commonly advection (QA) plays a role within the energy balance, but the size of advective flows between neighbourhoods has not been well-documented (Grimmond et al, 2010). Therefore, the energy flows in Figure 3, will be used in this research. In the following sections the individual energy flows will be explained in more detail.

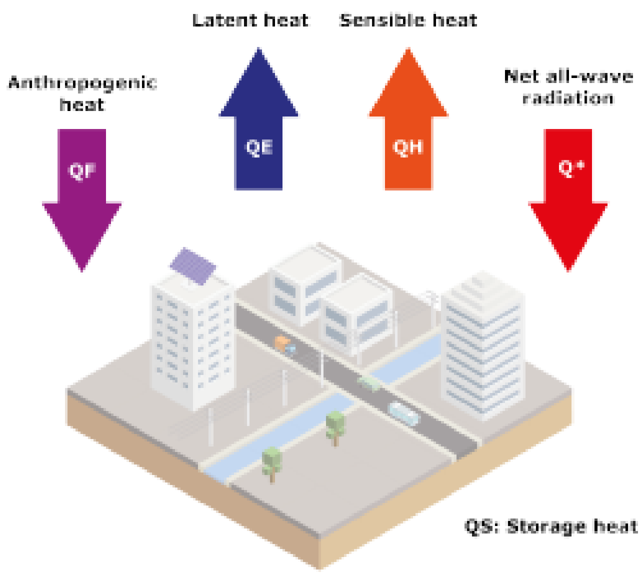


Figure 3: *Energy flows of the urban energy balance*

Net all-wave radiation (Q*)

The net all-wave radiation is a direct function of the absorption and reflection of short-wave radiation from the sun, during daytime, and the absorption and emission of long-wave radiation from the earth through radiative transfer, mainly during night-time. Both are modified by the geometric (plan density, building height, building uniformity and road orientation) and material properties (reflection and conductivity) of urban areas (Pearlmutter & Berliner, 2004).

Storage heat flow (QS)

The storage heat flow is the net uptake or release of energy by sensible heat changes in the UCL, buildings (materials), vegetation and the ground. The size of the storage heat flow is determined by the surface materials, urban structure and the resulting thermal mass (heat conductivity and capacity) (Grimmond et al, 2010). Values of QS can be two to three times higher in a city centre than their rural surroundings (Christen & Vogt, 2004).

Turbulent sensible heat flow (QH)

When an object or air is heated, its temperature rises because energy is added. Similarly, when energy is removed from an object and its temperature falls, the removed heat is called sensible heat. Thus, an energy flow that causes a change in temperature is called sensible heat. The turbulent sensible heat flow is driven by several phenomena, such as the net available energy, the ability of the air to transport the energy away from warmer locations (towards or away from the surface), and the gradient in air temperature between the surface and the air above it. The typical diurnal course of the turbulent sensible heat flow is related to the nature of the building fabric (a key control on the storage heat flow) and the available moisture including the fraction of green space (Grimmond et al, 2010). The amount of sensible heat varies greatly between rural and urban areas (Goldbach & Kuttler, 2013).

Latent heat flow (QE)

All pure substances in nature are able to change their state. Solids can become liquids and liquids can become gases, but changes like these require the addition or removal of energy. The energy flow that causes these changes is called latent heat. The turbulent latent heat flow depends on the availability of moisture at the surface (water-bodies, vegetation and wet soils), the sign and size of the surface–air humidity gradient and the ability of the atmosphere to transport moisture. The latent heat flow (QE) may be substantial in vegetated areas, but in areas dominated by dry surfaces, such as cities, this flow can be marginalized (Masson et al, 2002). The latent heat flow densities in mid-latitude cities show less evapotranspiration than their rural surroundings, because QE is mainly determined by vegetation, which is only a small fraction in urban areas. Additionally, faster run-off in the built environment lowers the availability of water.

Anthropogenic heat flow (QF)
The anthropogenic heat flow is a function of the number of vehicles driven within the area, the energy used within buildings, and the energy released as a part of the urban metabolism (Grimmond et al, 2004). This energy flow is often omitted in the urban energy balance, because of its small magnitude in residential settings, it is assumed to be embedded in other flows and the required data is often not available (Grimmond et al, 2004; Pearlmutter & Berliner, 2004). However, the anthropogenic heat flow in dense urban areas can play a major role in the surface energy balance.

Figure 4 gives an indication of the amounts of energy flows in dense urban environments (Grimmond et al, 2004).

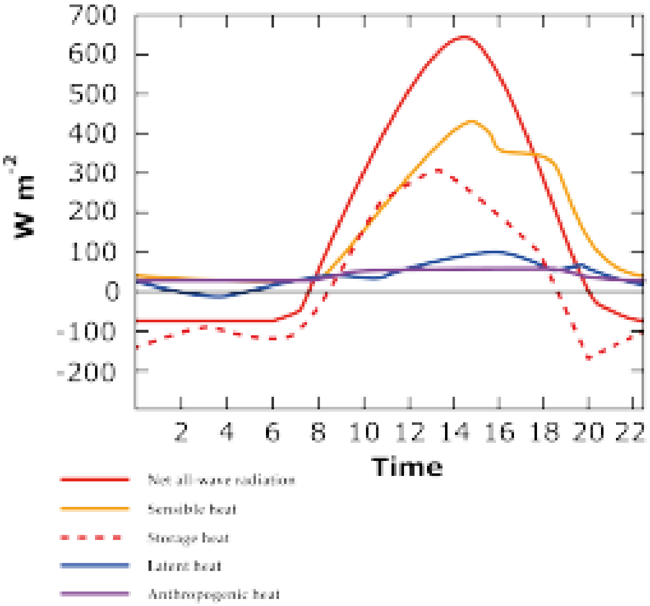


Figure 4: *UEB Marseille (Grimmond et al, 2004)*

Temporal variations of surface energy exchange
Urban energy flows are extremely dynamic. The energy flows within urban environments do not only vary diurnally, but also seasonally and annually. The dynamics of the urban energy flows in central London are displayed in Figure 5. The monthly diurnal patterns (coloured lines) and accumulated energy flows (for day- and night-time) are presented in bars.

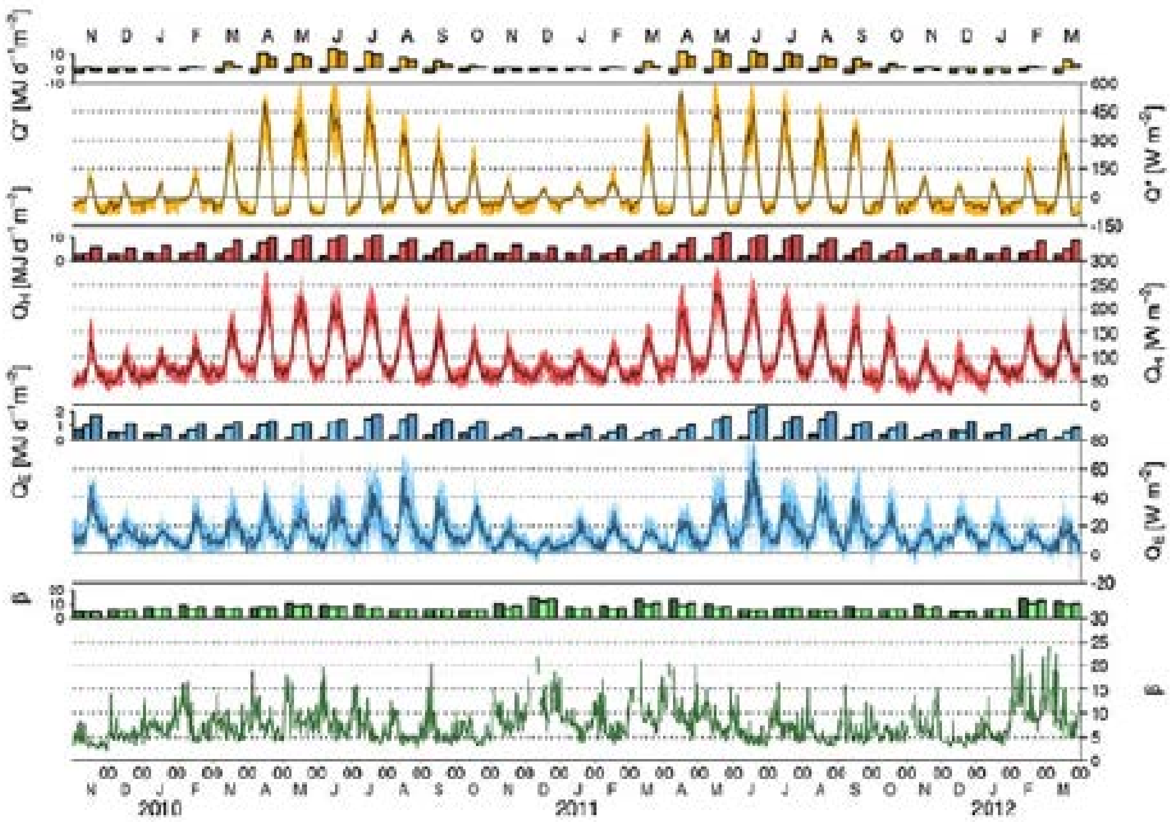


Figure 5: *Energy flow dynamics (Kotthaus & Grimmond, 2013). Q* is net all-wave radiation, Qh is sensible heat, Qe is latent heat, β is the Bowen-ratio (Qh/Qe).*

Wind

Although wind does not play a major role in energy partitioning in the urban environment, it is shaped by the urban climatic conditions. The air movement in urban spaces have great consequences for pedestrian comfort, building ventilation, air quality, energy use (Erell et al, 2011) and energy generation (Turkbeyler et al, 2011). Unfortunately, the irregularity of the urban terrain makes air-flow patterns in the built up areas extremely complex (Erell et al, 2011).

Wind is caused by differences in temperature. Pressure differences are created through ascending warm air, which subsequently attracts cold air (Lenzholzer, 2013). Wind can be observed at three different scale levels: (1) Macro-scale, which is influenced by the rotation of the earth and the main wind directions; (2) the local-scale, which is influenced by the difference in temperature between water and land, hills and valleys and urban heat-islands and their surroundings, and (3) the micro-scale where the wind flows are dominantly influenced by the geometry of the urban environment.

On average the wind on ground-level flows in a horizontal direction and is predominantly powered by the macro- and local wind patterns. Changes in the ground-level, due to topography, vegetation or built structures in urban areas, obstruct the wind flow and modify its pattern (Erell et al, 2011). Within the urban canopy layer the wind speed and direction are extremely variable. In general, observations show a drop in average wind speed below the roof level, but micro-scale changes in geometry may result in localized high wind speeds. These winds may be used for energy generation.

1.2.2 Renewable energy flows in urban microclimates

Urban microclimates influence the potentials to generate renewable energy (Shahrestani et al, 2015; Turkbeyler et al, 2011). The microclimate parameters and potentials for renewable energy technologies are significantly influenced by urban textures and neighbouring buildings. This underlines the need for a radical change towards considering microclimates for planning and design (Shahrestani et al, 2015).

Within urban environments, there will generally be a range of renewable energy options available; wind, solar, biomass and geothermal energy. It is essential to select a mix of renewable energy sources, along with some energy storage mechanism to best utilize the resources and ensure a continuity of energy supply. The best combination will typically depend on the local climate, geology and terrain (Macleod, 2008). Urban environments are best suited for small scale energy generation. Small scale energy generation, or microgeneration, is the process of energy generation on a small scale to supply the energy demands of low-consumption buildings, such as domestic dwellings, or small communities. The objective may be in-dependency from the electrical grid, but typically to reduce the direct consumption of fossil fuels (Macleod, 2008).

Knowledge of the microclimatic variables, especially urban wind patterns and solar radiation can be effective for developing better design options for renewable energy technologies within the urban environment (Turkbeyler, 2011). However, achieving these solutions in dense urban environments is challenging. This is mainly due to the complex nature of the heat transfer mechanisms within urban areas, which are significantly different from those recorded by official weather stations located in suburban environments. The knowledge of microclimatic parameters, especially direct and diffuse solar radiation, air temperature, wind direction and speed are of great importance in developing better design options for building design and the implementation of renewable energy within the urban environment (Shahrestani et al, 2015). The implementation of renewable energy devices preferably takes place at the building design stage when the building location, orientation and structural elements can be optimized according to the available wind and sunlight (Macleod, 2008).

In the next section a range of energy microgeneration techniques will be discussed, including their potentials in the urban environment and their relation with urban microclimates.

Wind energy

In recent years it has been acknowledged that the renewable resource wind will be among the best alternative energy sources within the urban environment, because it is clean, affordable, safe and available in the long-term (Ishugah et al, 2014). So far, little work has been done on wind energy resource and its applications in urban environments, especially the study of urban wind speeds with a view on wind turbine applications has been neglected (Ishugah et al, 2014).

There are two approaches to integrate wind energy in urban environments. The first approach is to locate wind energy farms in the periphery of urban areas. The second approach is to integrate wind energy systems into the building design. The first approach comes with additional costs creating a supporting network and transport, while the second approach still has to overcome challenges of turbulence, noise, size, space and visual impacts (Ishugah et al, 2014).

The most useful wind for generating electricity is strong undisturbed wind that blows over flat surfaces. Urban areas consist of many objects that disrupt the wind flow, such as buildings, bridges and trees. The surface roughness of the urban environment results in high turbulent air zones above building structures. These zones influence the wind speed and direction and by that its extractable power. Therefore, wind turbines need to be placed high, preferably above the turbulent air, to capture the strongest winds (Heath et al, 2007). However, due to the combination of topography, building height and openings in the urban fabric, wind flows are constantly redirected and compressed. This can lead to local high wind speeds, which may be used to extract wind energy (Lenzholzer, 2013).

The phenomena described above, result in two obvious locations to place wind turbines. The first is to pole mount wind turbines on their own foundation and by this 'catch' wind from higher altitudes (Figure 6). The second option is to place wind turbines above, or around existing structures, where high wind speeds are expected (Figure 7). These wind turbines may also be integrated within building structures (Figure 8).

Figure 6: *Option 1: Pole-mounted wind turbine, Great lake Science Centre, Cleveland*

Figure 7: *Option 2:Rooftop wind turbines, Catholic University, Melbourne*

Figure 8: *Option 3: Building integrated, Bahrain world trade centre*

Solar energy

Solar energy has a considerable role to play in urban areas (Keirstead & Shah, 2013). An extensive application of solar radiation in urban areas seems to be essential and a practicable strategy, but has a great influence on the formation of cities to be totally effective. Solar systems include electronic or mechanical devices that modulate the sun's effect on a building, or collect, channels and transform sunlight in some form of energy. Photovoltaic panels (Figure 9), movable shading and solar thermal panels (Figure 10) are all active solar systems (Zeman, 2012).

Roofs and façades are the most logical places to integrate solar energy on the building level, but placement needs to be carefully considered as it significantly affects the architecture. When the integration of solar energy is taken into account in the early design phases, it is more likely to lead to more attractive solutions (Figure 11). The integration might be made easier when planners and designers are aware of the locations where most of the energy can be harvested (Kanters & Horvat, 2012).

The potential of solar energy on stand-alone buildings has been well studied (Li et al, 2015). Buildings within urban areas are not able to capture as much solar radiation as stand-alone buildings, due to the effects of mutual shading of surrounding buildings. Compactness is obviously a major parameter for urban form that affects the accessibility of solar energy in urban environments (Mohajeri, 2016). Other important criteria to take into account are the sun's angle and roof and façade characteristics.

Figure 9: *Option 1: Photovoltaic panels*

Figure 10: *Option 2: Thermal collectors*

Figure 11: *Option 3: Integrated, Solar city*

Biomass energy

Biomass includes all existing terrestrial organic matter and is the most important source for food, fodder and fibre production (Offerman et al, 2011). Currently the conversion of biomass contributes to approximately 10% of the world's annual primary energy supply (IEA, 2015). The largest part of bioenergy is currently used in developing countries for the purpose of heating and cooking. These applications are often characterized by low efficiencies and strong emissions (Offerman et al, 2011).

One unique feature of bioenergy is its diversity (Keirstead & Sha, 2013). There are multiple options to produce heat and power from biomass depending on the biomass type, technology type and size, and the degree of decoupling between the biomass treatment and conversion processes (Keirstead et al, 2012). Some examples of directly available biomass within urban environments are; biodegradable municipal wastes (e.g. household wastes and paper), urban wood waste (e.g. household waste, industrial wood wastes and construction wood) and waste vegetable oils (e.g. cooking oil wastes).

Most of the biomass applications in urban environments such as biodegradable wastes, do not directly influence the urban microclimate, except for bioenergy crops and plants (in public and private space). Bioenergy crops are plants which can be processed into energy such as willow and Miscanthus (Figure 12). Bio-energy crops can be cultivated and processed within the city boundaries. Organic wastes from the city can be used to fertilize the energy crops and by this create a closed loop. However, due to the low energy density (aprx. 0.5W/m2), bioenergy crops are more appropriate for peri-urban environments where more space is available. Besides bioenergy crops, building roofs and façades, make up a great amount of unused space within the city's boundaries. This unused space can be used to grow plants (Figure 13) or algae, which can be transformed into bioenergy as well.

Besides the benefit of energy generation from biomass, green areas in cities can improve the urban landscape (Robitu et al, 2006). Green areas can regulate the urban climate by increasing the moisture content of the air and by this reduce the air temperature and provide better comfort (Honjo & Takakura, 1990). Numerous studies show that the cooling effects of parks, due to the combined effect of evapotranspiration and shading, can result in a temperature reduction by 5 degrees Celsius (Robitu et al, 2006). Furthermore, shadows cast by vegetation can modify the cooling and heating loads of buildings by reducing the solar radiation and surface temperature (Simpson, 2002). However, vegetation reduces the wind speed and has a negative effect on natural ventilation, and convective cooling of building surfaces (Akbari, 2002).

Biomass can be used for a variety of commercially available technologies and it can be converted into fuel, electricity and heat. Due to these reasons, bioenergy is expected to play an important role in achieving a sustainable energy system. However, there are some specific concerns when integrating bioenergy into urban areas such as the availability of space to store biomass, the emission levels of bioenergy conversion processes and transport issues regarding logistics and costs of biomass supply (Keirstead et al, 2012).

Figure 12: *Option 1: Energy crops (e.g. Miscanthus sinensis), Houtan Park, Shanghai*

Figure 13: *Option 2: Vertical green wall, University del Claustro de Sor Juana, Mexico*

1.2.3 Visualization

To be able to comprehend the (renewable) energy flows in urban environments, clear and accessible communication tools are necessary. Communication is the main activity to increase an understanding of certain phenomena. While it is estimated that approximately eighty percent of the impression of our surrounding comes from sight (Bruce et al, 1996), the use of visualizations may contribute in making (renewable) energy flows understandable. Communication is the fundamental purpose of producing visualizations throughout the planning and design phases of any landscape, urban design or architectural project (Downes & Lange, 2015).
The link between seeing and understanding was the basis for the adoption of the term visualization by McCormick et al (1987). It was a new word, because in earlier dictionary definitions, visualization was restricted to the process of forming a mental image of, or envisioning, something (Bishop and Lange, 2005). The more recent usage of the word involved the process of interpreting something in the visual terms or, more particularly, putting something in visible form. McCormick et al. (1987) defined visualization in this way:

Visualization is a method of computing. It transforms the symbolic into the geometric, enabling researchers to observe their simulations and computations. Visualization offers a method for seeing the unseen. It enriches the process of scientific discovery and fosters profound and unexpected insights. In many fields it is already revolutionizing the way scientists do science.

So, visualizations can help people to envision. That is, to better understand the relationship between data or some condition of the environment (Bishop & Lange, 2005). Due to modern technical developments, urban systems generate complex and large data sets. Visualizations can make these large data sets understandable and accessible. Fortunately, for landscape architects and urban planners, the environment can be represented via a palette of analogue and digital media as an essential mean for communicating to experts and the public.
3D visualizations are currently used in a variety of fields from brain surgery to tv advertisements (Figure 14).

Figure 14: *3D visualization in an advertisement*

Visualizations inform, demonstrate, persuade and facilitate communication (Offenhuber, 2010). Moreover, 3D visualizations increase engagement, enhance learning and strengthen people's understanding of complex environmental issues (Sheppard, 2012). Creating a picture is one of the easiest ways of getting people to imagine something. 3D visualizations are able to make the invisible visible: Not physical in the actual landscape, or with abstract graphics, such as diagrams, but in virtual landscapes, placing what cannot be seen with the naked eye into contexts to which people can relate to (Sheppard, 2012).
Ultimately visualization will contribute to more informed decisions in (urban) planning and design. In order to achieve more informed decisions through visualization, Sheppard (1989) suggested that (landscape) visualizations should fulfill three fundamental objectives: (1) Convey understanding of the proposed project, (2) demonstrate credibility of the visualization itself, and (3) avoid bias in response to the proposed project. Credibility can be demonstrated by the use of evaluation. Evaluation is a crucial part in developing visualizations in order to build up defensibility and reliability. Sheppard (2001) proposed an interim code of ethics (Appendix 1), which support the goal of response equivalence and acceptability to the audience. Six principles provide guidance on the quality of the visualization:
1 Accuracy
2 Representativeness
3 Visual clarity
4 Interest
5 Legitimacy
6 Access to visual information.

Criteria 1-3 relate directly to issues of content validity. Criterion 4 addresses utility to ensure the viewer's engagement. Criterion 5 relates directly to validity and reliability. Criterion 6 addresses the concept of equity (equal access for stakeholders and public). Several of these principles were used during this research, to safeguard the quality of the new visualizations. The selected principles will be elaborated on in chapter 2 (Methods).

Variables in visualization

One of the first identifications of the major variables within the realm of (cartographic) visualization was proposed by MacEachren et al (1994). Along with other important distinctions, as proposed by Bishop & Lange (2005), these included:

1. Communication vs the discovery of knowledge
2. The level of interaction
3. Abstract vs realistic presentation
4. Dynamic vs static displays
5. Single vs multiple representations
6. Dimensions

The focus of this research is to communicate urban energy flows and less on the discovery of knowledge (identification 1). When a visualization is focused on communication, the level of interaction plays a less significant role (identification 2). Urban energy flows are highly dynamic, which means that multiple representations are crucial in representing dynamics (identification 5). Therefore, variables three, four, and six, will be elaborated on.

Abstract versus realistic presentation

Every visualization or simulation is a simplified representation of reality and therefore, it is important to decide what exactly to show. Abstract visualizations (Figure 15) generally require substantial degrees of familiarity of both the subject matter and display technique. Therefore, abstract visualizations are generally understood by domain experts (Bishop & Lange, 2005). On the other hand, visualizations with more detail (Figure 16) or realism are generally advantageous due to the sense of familiarity to the observer, assisting with engagement, orientation and credibility (Lovett et al, 2015). However, this needs to be balanced against the resource implications and the purpose of the visualization.

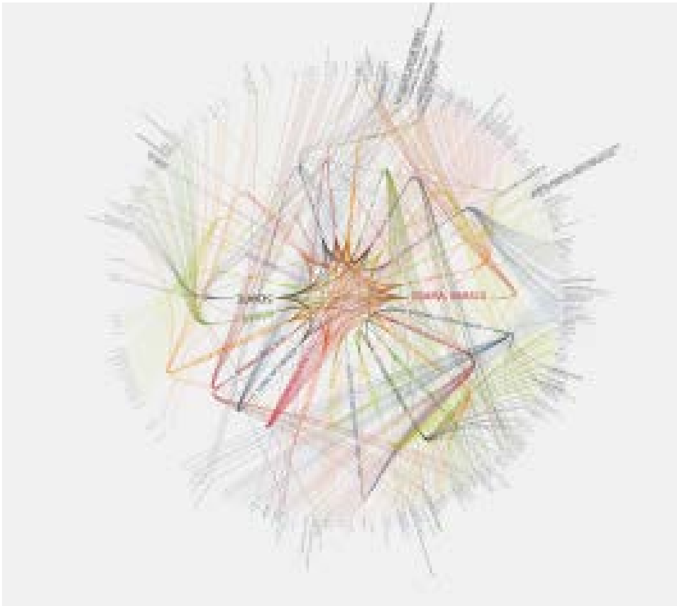


Figure 15: *Abstract data visualization*

Figure 16: *Realistic visualization*

Dynamic vs static views

Dynamic visualizations are continuously changing, either with or without intervention of the user (Slocum et al, 2001). One example is an animated map in which the display is constantly changing (earth wind flows: https://earth.nullschool.net). Another form is direct manipulation, in which the user can explore the data by interacting with it (Interactive maps of the municipality of Amsterdam: http://maps.amsterdam.nl/energie_gaselektra/?LANG=nl) (Bishop & Lange, 2005)

Dynamic displays may represent many different changes. In cartographic visualization, temporal phenomena are most commonly displayed dynamically, such as spatial distribution of data on sea surface temperature, pollution, population and mortality rates. In realistic visualization, the dynamics are generally more spatial (e.g. changing viewpoints) and would commonly be in the form of a walk- or fly-through (https://www.youtube.com/watch?v=-JV3FfmAnNnI).

Dimension

Maps are recognized as two-dimensional graphics and rendered buildings often as three-dimensional. However, there are many ways of representing two- and three-dimensional graphics and more distinctions can be made in terms of dimensionality (Bishop & Lange, 2005). Especially in (landscape) architecture, some representations are referred to as two and a half dimension (2.5D). 2.5D graphics try to simulate the appearance to be 3D, but in fact they are not. A famous technique used in architecture is parallel projection (also called orthographic projection). In these projections lines are parallel to each other, both in reality and in the projection plane. Orthographic projections can be sub-divided in axono-, iso-, di- and trimetric projections (Figure 17).

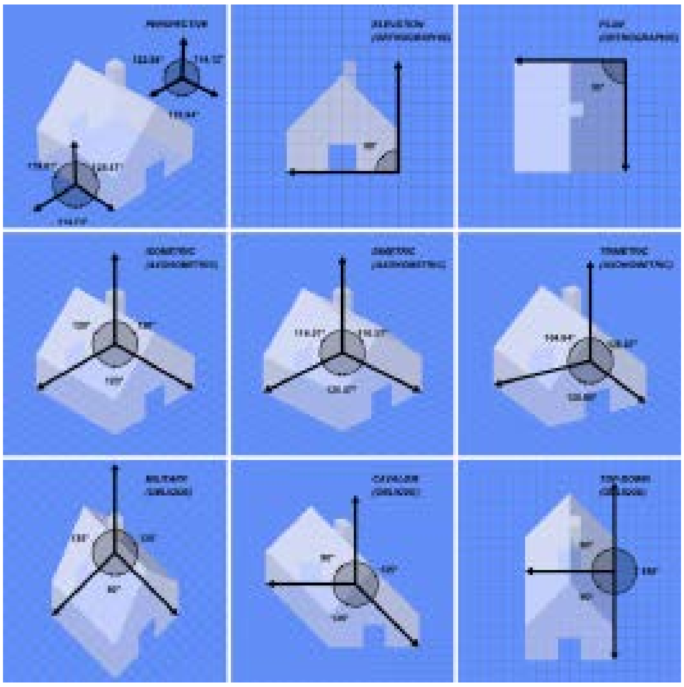


Figure 17: *Orthographic projections*

While 2D and 3D images are relatively easy to grasp as human beings, the fourth dimension (4D) is generally more complicated (Figure 18). The main component of the fourth dimension is the inclusion of time. For the natural sciences it is a dimension of the universe as a fundamental measurable value (Mertens, 2010). Time has a specific meaning in landscape architecture and planning. The way designs are used and perceived do not only depend on location and content alone, but to a large extent on time as well. The use of the fourth dimension is crucial in representing dynamic systems (Figure 19).

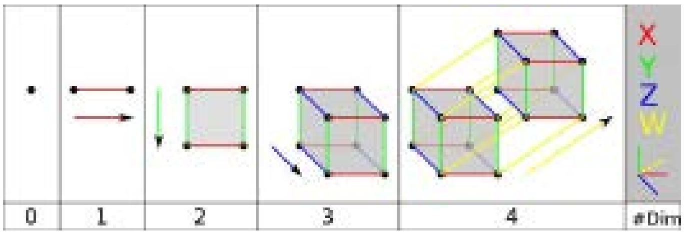


Figure 18: *Dimensions visualized*

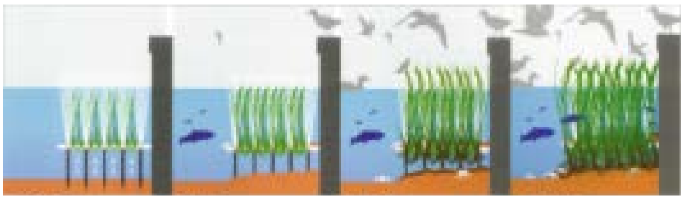


Figure 19: *Development of the 'fiber optic marsh', Rhode island, USA*

	Rendered still images	Animations	Real-time models
Visualization purpose	Can incorporate a high level of feature realism, though interactivity is generally limited	Useful when landscape dynamics (e.g. change over time) are important. Can convey a sense of movement through, or movement of, landscape features	Provides the interactivity that can be especially useful for engagement and collaborative functions
	Good for communication and education functions, especially where multiple possible changes or scenarios need to be shown on a comparative static basis	Particularly appropriate when movement needs to be combined with a higher level of feature detail than possible in real-time models	Feature realism may need to be limited, depending on availability of computer processing power and facilities for level of detail management
Visualization audience	Can reach audiences via a range of media including print, digital display at events and the Internet	Straightforward to display at events; possible to make available via the Internet although file size may be a concern for some viewers	Most effective in workshop settings. More immersive and interactive displays typically require participants to attend a meeting venue, though some models can be distributed via the Internet
Resources required	Much depends on the level of detail required. Representation of foreground features is particularly important for ground-level views	Prepared in advance of use. Compiled animations require more effort than single still images but less than a real-time model. Animations recorded from real-time models may require supplementary editing	Can be demanding in terms of both preparation time and equipment needed for model creation and presentation, although display may also be possible on standard hardware. A panoramic display capability is particularly advantageous
Communication	Detailed representations and straightforward links to contextual information can enhance credibility. Salience depends on the viewpoints provided	Can provide a balance of credibility and salience, though the predefined nature of content may limit both aspects. Movement gives limited interactivity and immersion which may increase engagement	Exploratory capabilities can increase salience for stakeholders. The novelty can capture initial interest and may increase engagement
Strengths communication weaknesses	Viewer has a passive role so engagement may be limited. Predefined viewpoints make it difficult to respond to audience requests for alternative perspectives	Predefined viewpoints make it difficult to respond to requests for alternative perspectives or to compare before and after views Internet distribution requires manageable file size, reducing frame size and/or image quality	Limits on detail can impair credibility in certain situations. Immersive motion is disconcerting or uncomfortable for some viewers

Figure 20: *Landscape visualization methods (Lovett et al, 2015)*

Visualization techniques

The goal of this research is to make energy flows intelligible for (urban) planners and designers. Therefore, it is important to find out which visualization techniques are able to visualize dynamic urban energy flows. There are many visualisation techniques available, but only the most relevant techniques for the representation of energy flows in urban microclimates will be discussed. Four disciplines were further examined: Landscape visualization, flow visualization, climatic (flow) visualization and energy flow visualization.

Landscape visualization

To appropriately visualize (parts of) landscapes, visualizers will have to make trade-offs in areas of detail, interactivity, resources available and the demands and aims of the intended end-users (Appleton et al, 2002). The three main Computer-Aided-Design (CAD) and Geographical Information System (GIS) methods regarding visualization purpose, audience, available resources and communications strengths or weaknesses are shown in Figure 20 (Lovett et al, 2015). The three main methods are categorized in still images (or scrolling panorama's) from defined viewpoints, animated sequences (fly-through's along specified paths or changes over time) and real-time models (or virtual worlds), where the user is able to navigate freely through the landscape.

Visualizing flows

Understanding and representing the complexities of flow structures has been a subject of interest for many centuries. Understanding and predicting flow behaviour affects our daily life and safety by applications ranging from cardiology of aircraft design to global climate and weather predictions (Svakhine et al, 2005). In the last century, many experimental visualization techniques have been applied to capture and depict flow characteristics. These techniques range from photography to dye injection (Figure 21). Many of the applied techniques involve a reduction of detail and use lower-dimensional (1D/2D) structural information to depict flow characteristics. These techniques created some stunning and scientifically meaningful imagery, but showed to be time-consuming, expensive and not applicable to large scale problems (Svakhine et al, 2005).

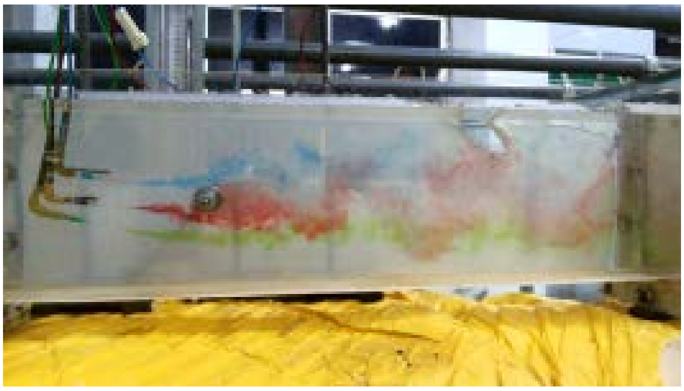


Figure 21: *Dye injection*

According to the different needs of the users, there are different approaches to flow visualization. A distinction is made between; 1. Direct flow visualization, 2. Texture-based flow visualization, 3. Geometric flow visualization, and 4. Feature-based flow visualization. This research merely focuses on the direct flow visualization (Figure 22: left). Direct flow visualization techniques are the most primitive methods of flow visualization. In direct visualization the data is directly mapped to a visual representation, without complex conversions or extraction steps (Post et al, 2002). Direct flow visualization techniques are computationally inexpensive and simple to implement. Direct visualization allow for immediate investigation of the flow field. However, they may suffer from visual complexity and the lack of visual coherency. Furthermore they also suffer from serious occlusion problems when applied to 3D data sets (McLoughlin et al, 2010)

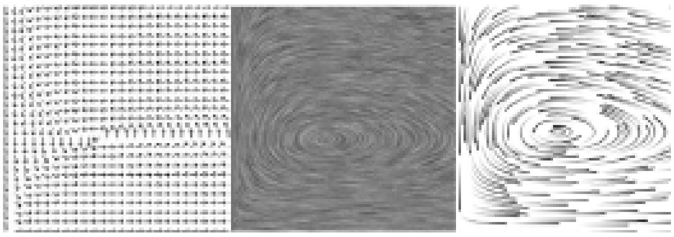


Figure 22: *Flow visualization techniques. Direct- (left), texture based- (middle) and geometric (right) visualization (Hauser et al, 2003)*

Visualizing climatic flows

Climatic phenomena are predominantly visualized by atmospheric researchers (Nocke et al, 2007; Häb, 2015). Atmospheric researchers are frequently restricted to the standard visualization techniques, such as 2D diagrams (Figure 23), scatterplots and coloured 2D maps (Figure 24). These (static) visualizations are commonly created by using statistical tool-kits, including MS excel, R and ArcGIS. While the currently used visualization techniques are easily understandable, they are frequently restricted to summarizing time series or scatterplots without including the spatial context (Nocke et al, 2007). Thus, interesting features or patterns in the data might remain undetected, especially for spatial oriented disciplines like (landscape) architecture and urban design. On the other hand, in recent years many interactive visualization techniques for atmospheric data sets have been developed, especially for global and regional scale datasets varying from observations, simulations and remote sensing (Häb, 2015). While there has been an increase in visualizations of large scale weather and climate data, examples for the visualization and analysis of urban (micro)climate datasets are still limited (Häb, 2015).

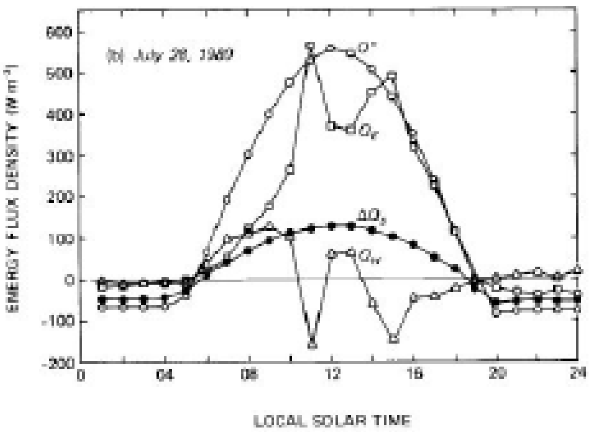


Figure 23: *UEB in a 2D diagram (Oke, 1988)*

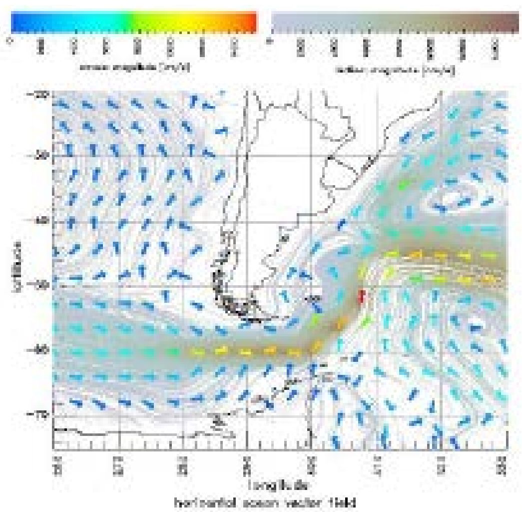


Figure 24: *Ocean currents in a 2D map (Nocke et al, 2007)*

Visualizing energy flows
Over the past 100 years the most well-known technique for visualizing energy- and material flows are Sankey diagrams (Figure 25). Sankey diagrams are abstract, or diagrammatic visualizations and consist of arrows varying in width, where the width indicates the relative magnitude of the flow and the direction indicates the connection between sources and sinks for each flow (Abdelalim et al. 2015; Schmidt 2008).

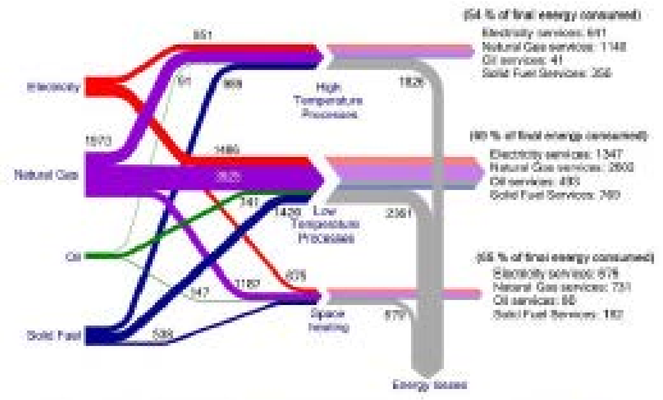


Figure 25: *Sankey diagram depicting the energy flowing through industrial heating processes in the UK*

Sankey diagrams are important in showing the energy flows from source to sink, but are often static in character and without a (urban) spatial component. Although, recent attempts have been made to include the third dimension, interactivity and spatiality (e.g. EnergyViz) in Sankey diagrams (Alemasoom, 2016). Sankey diagrams can be developed easily, because energy- and material flows are commonly stable. Climatic energy flows on the other hand, have a much more dynamic character.

Energy flow visualizations involving the (urban) spatial context were developed during the 1970's (Figure 26). These visualizations were part of the concept called 'urban metabolism'. The concept of the urban metabolism, conceived by Wolman (1965), is fundamental in developing sustainable cities and communities. The study of urban metabolism involves the 'big picture' quantification of the inputs, outputs and storage of energy, nutrients, water, materials and wastes for an urban region. The concept of urban metabolism has been researched over the past 45 years and research accelerated in the last decade (Kennedy et al. 2011).
The concept of urban metabolism can be defined as 'the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste' (Kennedy et al, 2007).

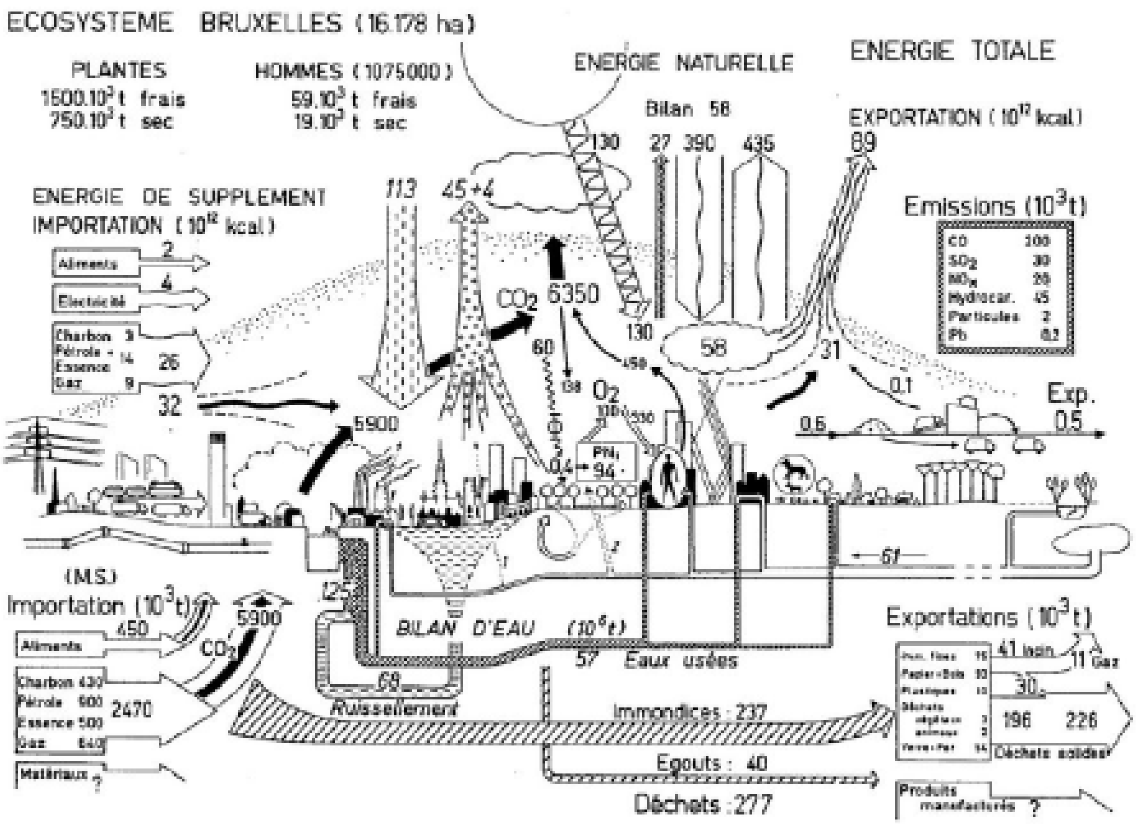


Figure 26: *Urban metabolism of Brussels (Kennedy et al, 2011)*

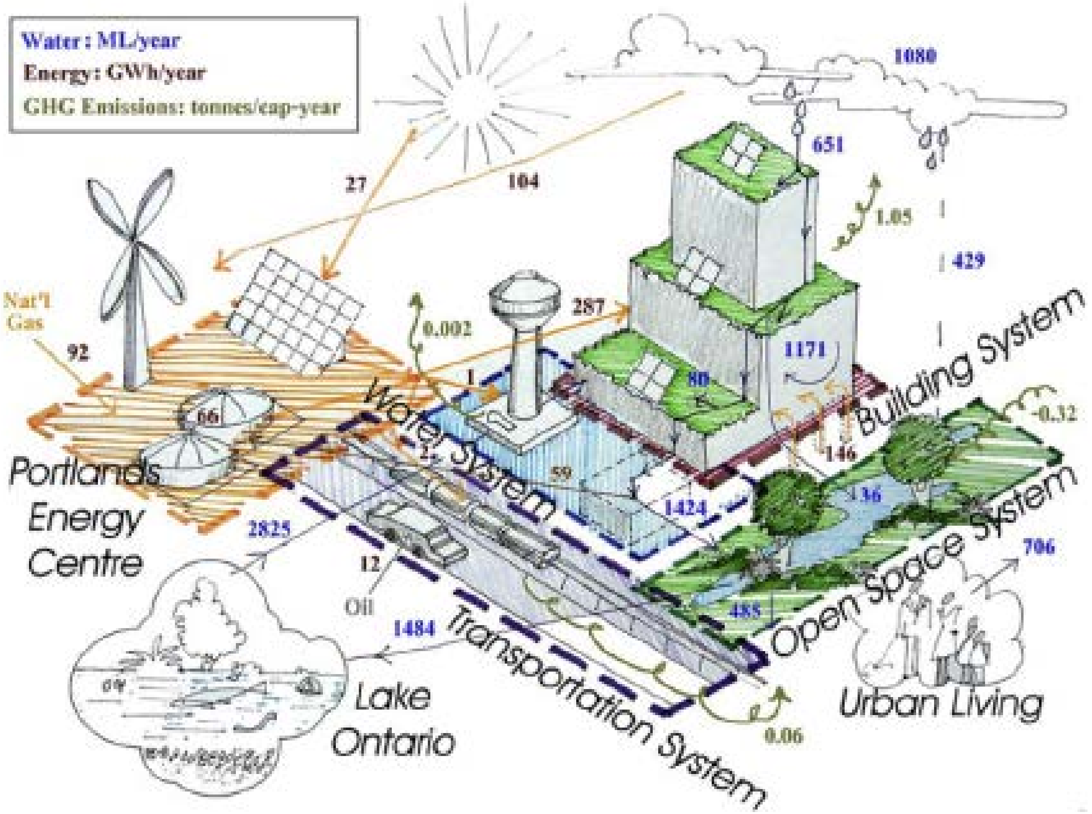


Figure 27: *Representation of a sustainable metabolism for the Toronto Port Lands, designed by graduate students at the University of Toronto (Kennedy et al, 2011)*

The potential of urban metabolism in an urban design context is a relatively new development. One of the first attempts to move beyond analysis to design is described in Netzstadt by Oswald and Baccini, 2003 (Kennedy et al, 2011). Urban metabolism has also been used as a tool to guide sustainable designs by civil engineering students at the university of Toronto. The students were challenged by design at the neighbourhood scale, involving the integration of various infrastructure using the concept of neighbourhood metabolism (Figure 27). They traced flows of water, nutrients, energy and materials through the urban system. Closed loops were created, which reduced the input of resources and output of wastes (Kennedy et al, 2011). New types of visualizations were experimented with (Figure 27). In this visualization the students used (static) parallel projection techniques and arrow symbols to indicate flows. Unfortunately, too many components were displayed, which led to severe occlusion. Some climatic flows were included (e.g. solar energy and evaporation), but were not represented in a comprehensible manner. Kennedy et al (2011) are calling for a mainstream practice of identifying resource flows for urban developments. However this requires the design community to be much more acquainted with the material and energy flows (Kennedy et al, 2011).

Recently a new approach has been developed to represent energy flows (not climatic energy flows). This new approach involved the use of particle systems. Particle systems are well-known in computer graphics. These systems are primarily designed to represent natural 'fuzzy' objects such as, water, rain, smoke and fire (see: https://www.youtube.com/watch?v=NuDHD-dpWlA). In the past these objects have been a huge challenge for computer rendering, because of their complex and irregular behaviour (Dudarev et al, 2013). However, in recent years' computer power has increased and researchers started to render fountains (Liang & Zhou, 2009) and fire (Zhou et al, 2006) using particle systems.
One of the most important task of these simulations was to understand how the system works and how to influence it (Dudarev et al, 2013). Energy flows can be rendered by using complex objects consisting of many small particles. Particle system simulation can clearly show the source and the consumer of en-

ergy. This and other characteristics of the system can be effectively used to increase an understanding of energy flows (Dudarev et al, 2013).
The particle system consists of three stages (Figure 28): generation, dynamic changes and death. A lifespan begins with the generation of particles (any shape) through an emitter. This emitter can be a single point or different types of surfaces (square, plane, circle etc.). The emitter controls the settings of the particles such as, number, speed and direction. The generated particles will die if lifetime reaches zero.

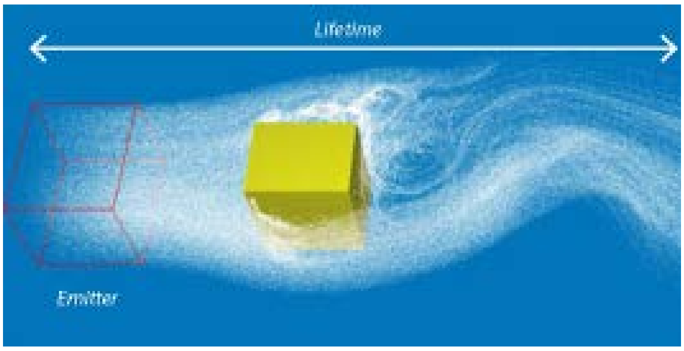


Figure 28: *Particle system*

Particle systems consist of a variety of characteristics. Each characteristic can be adjusted to fit the desired outcome. By adjusting the parameter of the particles, it is possible to change the simulation. The following characteristics of particle systems can be identified:

- Particle opacity (transparency and intensity);
- Particle size;
- Particle colour;
- Particle velocity (speed and direction);
- Particle initial position;
- Particle lifetime.

1.3 Towards a new visualization method

The literature clearly shows that there is a lack of visualization methods to communicate (climatic) energy flows into mainstream urban planning and design. This is partly due to the fact that current static and numerical models are unable to communicate energy flows in a concise and understandable manner and the failure of urban climatology in general to communicate its scientific knowledge in an accessible and applicable way (Mills, 2014).

This research will focus on energy flows within the urban canopy- and roughness sub-layer, because these layers are affected by interventions made by urban planners and designers. The energy flows of the urban energy balance will be included in the new visualization method, except for the advection flow. Wind flows will be included in the research, partly because of its effect on renewable energy generation. Besides energy flows, the most promising renewable energy flows (solar-, wind- and biomass energy) will be included. Geothermal energy will be excluded, because its effect on the urban microclimate and vice versa, has been understudied.
Due to the great variability and dynamics of the energy flows, this research will primarily focus on the day- and night variations and will exclude seasonal and annual variations. This is mainly due to the fact that the summertime climatological conditions are most valuable to investigate, regarding the thermoregulation of cities.

1.3.1 Research questions

The aim of this research is to make the energy flows in urban microclimates and potentials to generate renewable energy, intelligible for planners and designers. This will be achieved through the use of a new visualization method.
The research criteria for this research are partly adopted by the interim code of ethics (Sheppard, 2001) and include: Legibility (the ability to ‘read’ the visualizations), comprehensibility (the ability to understand the visualizations), attractiveness (the ability of the visualizations to hold the interest of the viewer), and usability (the ability of the visualization to be useful in urban planning and design).

Research question: What type of visualization can make energy flows (microclimatic and renewable) intelligible for urban planners and designers?

Sub-questions:

1. Are the new visualizations legible?
2. Are the new visualizations comprehensible?
3. Are the new visualizations attractive?
4. Are the new visualizations useful for (urban) planners and designers?

Chapter 2

METHODS

2.1 Research for- and through designing

Several research methods were used to develop a new visualization method (Table 1, page 20). The literature study that formed the theoretical background of this research, can be seen as 'research for design' (RFD). This study informed the design to improve its quality and to increase its reliability (Lenzholzer et al, 2013).
The second part of the research focused on the development of a new visualization method by 'research through designing' (RTD) (Lenzholzer et al, 2013). In this case RTD included the translation of specialist knowledge (urban climatology, renewable energy and (flow) visualization) into new visualizations. Subsequently, the new visualizations were constantly reviewed and adapted, which resulted in a cyclic process (Table 1).
To develop the new visualization method, the five main steps for visualization creation by Sheppard (2012) were applied, which will be elaborated on in paragraph 2.2:

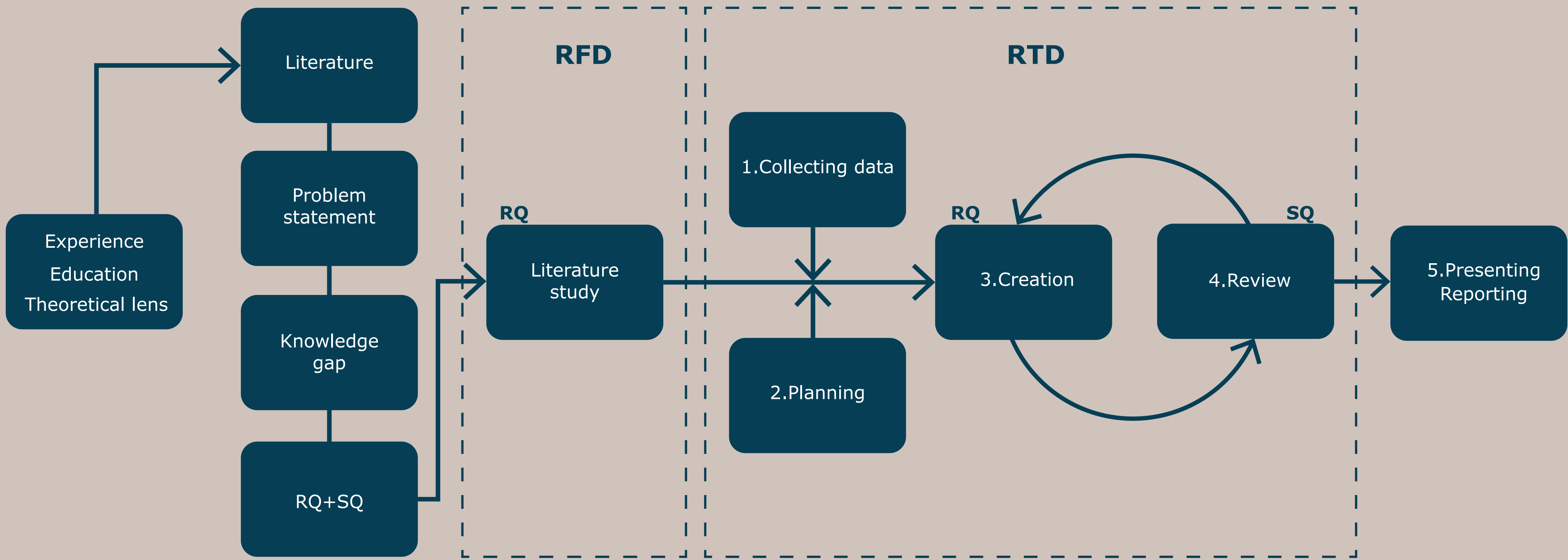
1. Collecting data
2. Planning
3. Creation
4. Review
5. Presenting

The variables of visualization (see page 11) were important for the development of the new visualizations. In table 2, the relevant visualization variables are shown on the left and the assessed disciplines on the top. Because the purpose of the new method is to educate professionals in the field of urban planning and design, the method should be seen as a tool for communication. The fourth dimension (4D) of time was included, to represent the dynamics of the energy flows. Animations were selected as a main visualization technique to visualize the dynamics of the energy flows. Animations are useful when landscape dynamics are involved, because they can convey a sense of movement (Lovett et al, 2015). Animations are advantageous over still images, because of their static character and over real-time models, because of their time and cost implications. It was impossible to represent energy flows in a realistic manner, because (most of) the energy flows are invisible to the human eye. Therefore the use of abstractions were essential in developing new visualizations. The most useful techniques of the four disciplines are displayed at the bottom of the visualization matrix. Several of these techniques were experimented with, including (4D) animations and particle systems.

	Landscape visualization	Climate visualization	Flow visualization	Energy flow visualization
Dynamic VS Static	Both	Static	Both	Static
Dimensions	Up to 4D	Mainly 2D	Up to 4D	Up to 3D
Abstract VS Realistic	Both	Abstract	Both	Abstract
Useful techniques	Animations	Streamline + arrow visualization	Direct + illustrative flow visualization	Particle flow visualization

Table 2: *Visualization matrix*

Methodological framework



RFD = Research For Design
RTD = Research Through Desinging

RQ = Research question
SQ = Sub-questions

Table 1: *Methods*

2.2 Research design

1. Collecting data

Visualizations may use data to increase their validity and reliability. For the new visualization method, data was needed to be able to communicate the energy flow characteristics (e.g. amounts of energy). Therefore, data of energy flow observations was essential. The results of a variety of measurement studies were the main input for the new visualizations, ranging from city centres to urban parks (London: Kotthaus & Grimmond, 2014; Basel: Christen & Vogt, 2004; Marseille: Grimmond et al, 2004; Stockholm: Bäckström, 2006). If there was no measured data of certain energy flows available, educated guesses were made. Furthermore, it should be taken into account that the visualizations focus on the aspect of communication and do not represent real life situations. The used measurement studies merely gave an indication of the amounts of energy flows.

To make a distinction between urban microclimates, the local climate zone (LCZ) classification of Stewart and Oke (2012) was applied in this research. LCZ's are formally defined as regions of uniform surface cover, material, structure and human activity that span hundreds of meters to multiple kilometres in horizontal scale. Each LCZ is individually named and ordered by one (or more) distinguishing surface property, which is often the height of objects (e.g. buildings) or the dominant land cover (Stewart and Oke, 2012).

The LCZ map of Amsterdam (Appendix 2) was used to identify the most present LCZ's. This map revealed that compact mid-rise and open mid-rise were most present in the city of Amsterdam. Compact mid-rise, consists of a mix of mid-rise buildings (3-9 stories) with few or no trees and mostly paved land cover. Open mid-rise consists of an open arrangement of mid-rise buildings with an abundance of pervious land cover (low plants, scattered trees) (Stewart & Oke, 2012). A third LCZ was selected to represent the differences between the energy flows in built (e.g. city centre and residential) and non-built (e.g. park) environments. This LCZ exhibits a lightly wooded landscape of deciduous and/or evergreen trees. The land-cover is mostly pervious (low plants) and the zone function is urban park (Stewart & Oke, 2012). The three LCZ's formed the basis of the new visualizations. To understand the LCZ's more easily, they were renamed for communication purposes (compact mid-rise = city centre, open mid-rise = neighbourhood, scattered trees = park).

2. Planning

In this research the target audience consists of (semi-) professionals in the field of urban planning and design, although other disciplines may benefit from the visualizations as well. The main purpose of the visualization is to educate professionals in the field of urban planning and design about urban energy flows, but eventually it may also be used as a tool for analysis, design and representation.

Visualization media options and software programs are numerous and evolve rapidly. Applying the appropriate software to develop the visualizations was essential. Software known by urban planners and designers would make the visualization more accessible. Unfortunately, known software programs such as, Google Sketchup and Autodesk AutoCAD, are limited in the use of animations and are not able to visualize particle systems. Therefore, a more advanced 3D program was required. A wide variety of specialized 3D programs is available, but most of these programs are expensive (e.g. Cinema4D, Rhino and Maya). To make the visualization widely accessible, a more affordable program was required. Therefore, the software program Blender (3D) was selected. Blender has many advantages over other 3D programs, because it is free and open source. Moreover, Blender is quite extensive and there are many tutorials available. Furthermore, there is a large community, which can be helpful if problems occur. Finally, Blender is compatible with many other well known software programs, such as Google Sketchup and Autodesk AutoCad.

Because meteorological measurements were not conducted during this research, the resources required to develop the visualizations were relatively low, although a graphically powerful computer saves rendering time.

3. Creation

The new visualizations were created by research through designing. The developed visualizations included the urban (renewable) energy flows in three different LZC's 1. City centre, 2. Neighbourhood, 3. Park.

The visualization variables (level of realism, dimension etc.) and the particle characteristics (speed, size, etc.) were important in developing a new visualization method. The visualization- and particle characteristics were experimented with, to develop a range of visualizations (designs). The most relevant visualization variables for this research are explained in detail below.

Level of realism

An appropriate level of realism is essential in understanding and communicating urban energy flows. Non-visual phenomena (most of the energy flows) are impossible to visualize in a realistic manner. Therefore the flows had to be abstracted. This was achieved by the use of particle systems. The particle characteristics (parameters) were adjusted to visualize the variety of energy flows. The differences between each flow were visualized by their particle colour, initial position and lifetime. Each flow had their own particle colour; short-wave radiation (yellow), long-wave radiation (red), anthropogenic heat (purple), sensible heat (orange), latent heat (blue) and storage heat (yellow = cold, red = warm). By assigning colours to each flow individually, they were more easily understood and separated. Different particle parameters were experimented with, to make the energy flows intelligible (Figures 29-31). The focus of the visualizations had to be on the energy flows, therefore the built up environment (microclimate) was displayed as simple as possible. In this way the viewer did not get distracted or dazzled by the visualization.

Figure 29: *Incoming short-wave radiation: Random particles (lines)*

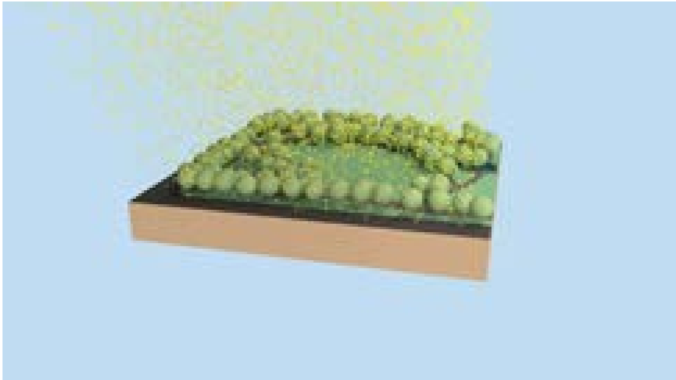


Figure 30: *Incoming short-wave radiation: Random particles (dots)*

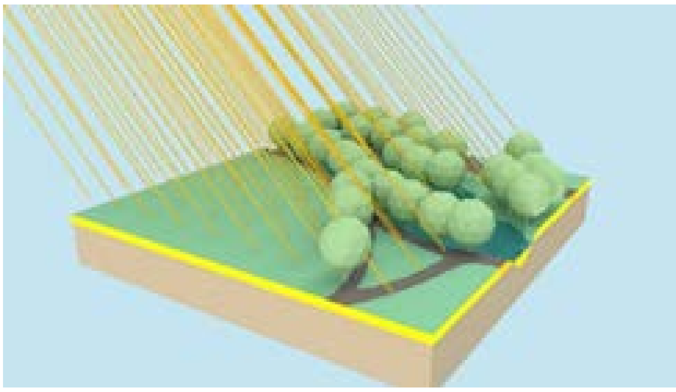


Figure 31: *Incoming short-wave radiation: continuous particles (dots)*

Dimension and scale

From the literature it became clear that including the fourth dimension would fit the visualization purpose. This was achieved by the use of an animated 3D model, which will be discussed in the animation section below. A variety of scales were experimented with, from 2000x2000m (Figure 32) to 25x150m (Figure 33).

Figure 32: *Scale 2000x2000m*

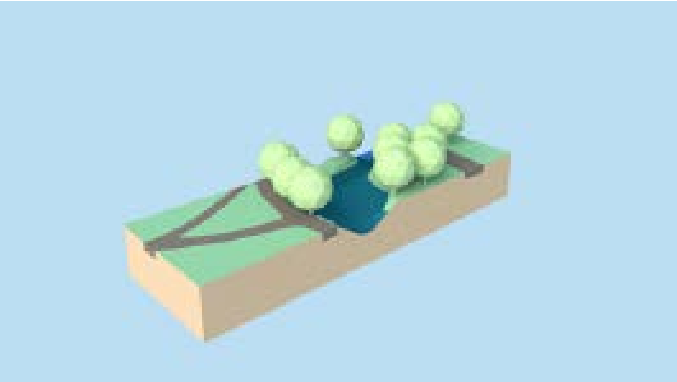


Figure 33: *Scale 25x150m*

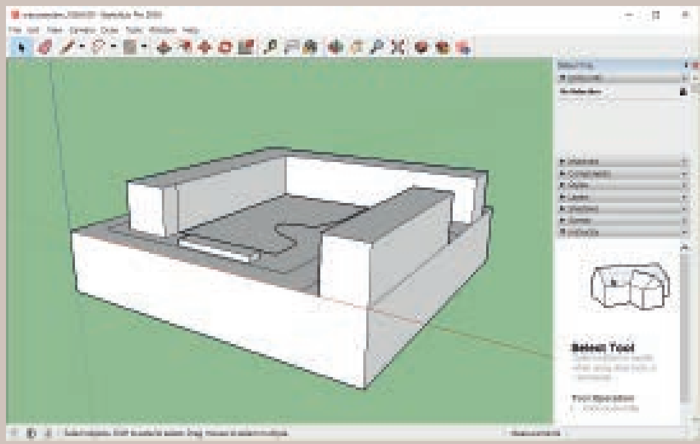
Animation

Animation in Blender is achieved through frame-by-frame animation. This type of animation is accomplished by subsequently showing still images at 24 frames per second. At this frame-rate (24 frames/second) one can recognize the idea of movement. By using animation, the speed of the particles can be adjusted. Furthermore, by animating the camera, viewers would have multiple viewpoints at the 3D model, which creates a better 3D experience. In this research different experiments were conducted regarding particle speed (fast: https://www.youtube.com/watch?v=rGpBBfenO0Q, and slow: https://www.youtube.com/watch?v=5iUFGnLhIZU) and viewing points.

Visualization workflow

1 Google Sketchup

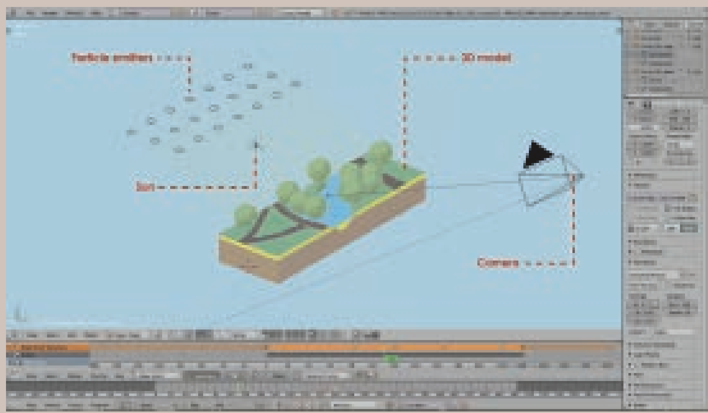
- Draw or import a 2D map
- Make faces (s4u Make face plugin)
- Extrude faces
- Export 3D model (using BlendUP plugin)



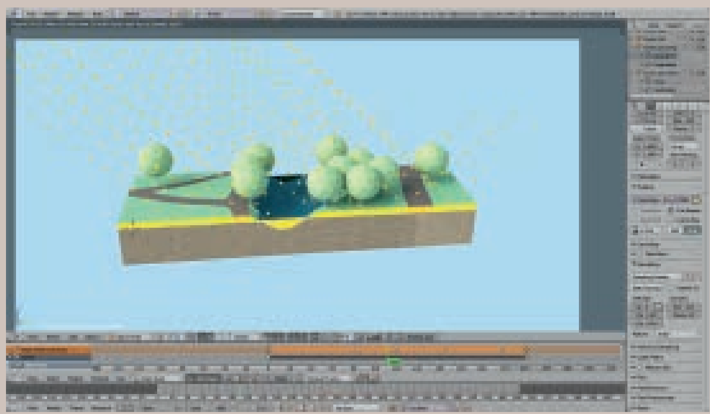
Simple 3d modelling in Sketchup

2 Blender

- 3D model opens automatically with BlendUP plugin
- Go to cycles render view
- Add light (sun)
- Add particle systems to your own preferences (object shape, color, 2D or 3D etc.)
- Add textures/materials to 3D model
- Add collisions to 3D model elements (permeability, sticki-ness etc.)
- Add camera
- Animate camera along a path (by adding keyframes)
- Render animations (mp4)



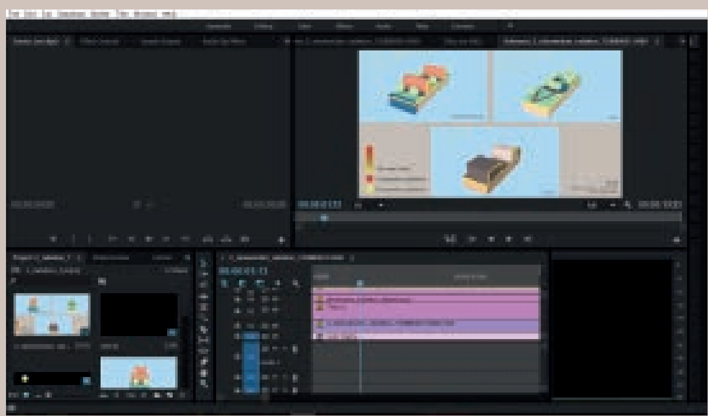
Visualization elements in Blender



Rendering in Blender

3 Adobe Premiere Pro

- Import mp4 files
- Sequence animations (speed, duration, etc.)
- Add text/titles
- Add original data as 2D image



Video-editing in Premiere Pro

Table 3: *Work flow*

Work flow
A variety of software programs were applied to develop the new visualizations (Table 3). Google Sketchup was used to develop a simple 3D model of the relevant local climate zone. More advanced users of Blender can develop this simple 3D model in Blender, instead of Google Sketchup. Once the 3D model was imported in Blender, several steps needed to be taken to add colours or textures to the 3D objects and to add particle systems and collisions to the model. When all the desired particle characteristics were entered, the model could be rendered in an animation. Once the animation was rendered, it was imported in a video editing program Adobe Premiere Pro. In Premiere Pro the animation properties (speed, duration etc.) were adjusted and titles added.

4. Review
An important aspect to build defensibility and quality of a visualization, is to involve community input. The community can help to derive the right decisions, and the community is able to objectively see things that the visualization preparer cannot. The visualizations can be revised afterwards and will lead to a final visualization, which can be more confidently explained to the audience (Sheppard, 2012). Two methods of community input were applied during this research.

The first involved community input by (semi-)professionals, during group meetings. These (semi-)professionals were either (landscape)architects, meteorologists or MSc students involved in microclimatic research. Every three weeks the (semi-)professionals gave feedback on the developed visualizations in group meetings.

The second method involved community input by 13 students in landscape architecture and spatial planning (3rd year BSc or higher) of the Wageningen University. A survey was conducted to review the quality of the new developed visualizations (version 1.0). After a short introduction of the research, the questionnaire (Figure 34) was distributed via personal computers. A distinction was made between specific questions (for each visualization) and general questions (for all visualizations together). The four research criteria were included in the questionnaire (left column, Figure 34).
The results of the survey were processed in SPSS and Microsoft Excel. Subsequently, the results were used to improve the visualizations.

Assessment area	Metrics	Question
Legibility	vieuwpoints	Q1: The visual has enough viewpoints
	particle amount	Q2: The visual has the right amount of particles
	clear components	Q3: The 3D components (buildings, trees etc.) increase legibility
	abstraction level	Q4: The visuals have the right abstraction level
	animation	Q5: The use of animation increases legibility
	colours	Q6: The use of colours enhance clearity
Comprehensibility	intuitivity	Q7: The visual is intuitively comprehensible
	pre-knowledge	Q8: There is no pre-knowledge is required to understand the visual
	particles	Q9: Animated particles show energy flows well
	comprehensibility	Q10: The visuals make you understand energy flows in the microclimate more easily
	colour transitions	Q11: The colour transition (storage heat) is clear
Attractiveness	attractiveness	Q12: The visual is attractive
	interest	Q13: The visuals hold your interest
Usability	information	Q14: The visuals are informative
	useful	Q15: The visuals are useful in future plans & designs
	technique	Q16: The used visualization technique is appropriate

Figure 34: *Questionnaire*

5. Presentation

When animation is involved, specific presentation techniques are required. There is commonly a variety of presentation techniques available, ranging from Powerpoint presentations to web-based formats. It is important to communicate the visualizations effectively to the target audience, without ignoring the context of the visualizations. The context, or pre-knowledge, is essential to take into account, because the visualizations cannot be comprehended in isolation. To be able to display the context and increase accessibility, multiple presentation modes were used (Sheppard, 2001). Furthermore it was important to show non-visual information during the visual presentation, using a neutral delivery (Sheppard, 2001). Three different presentation modes were used to represent the urban energy flows. These included a survey, (Powerpoint) presentations and web-based formats (online).

Survey

During the survey the animations (visualizations) were displayed using Microsoft Powerpoint. Within Powerpoint the viewers had the freedom to start and stop the animations at any given time. Non-visual information was given verbally at the start of the survey and by the use of recorded explanations during the animations in Powerpoint.

Presentation

The visualizations were presented multiple times by the use of a Powerpoint presentation (expert meetings, green-light, colloquium). The visualizations were displayed by using a beamer, tv or computer. Non-visual information was given verbally, to explain the context.

Web-based (online)

This research report functions as a context medium for the visualizations. The visualizations were made accessible, via website links (on Youtube.com). These links were unlisted, which meant that people could only access the visualizations if they possessed the specific website link. This prevented that the visualizations would be taken out of context.

2.3 Discussion of methods

Data and software

The availability of microclimatic datasets is limited, especially in dense urban environments. This limitation obstructed the assessment of the amounts of energy. On the other hand, completely accurate data was not a necessity in order to communicate the urban energy flows. The visualizations were able to show differences in energy flow amounts and the relationships between several energy flows within a variety of local climate zones. Furthermore we have to take into account that, for communication purposes, the visualizations contain a high level of abstraction. This means that many detailed, but important (climatological) aspects, were omitted (e.g. shadows, sky view factor and advection).

Blender showed to be an appropriate software medium for the visualization purpose. Advantages of using Blender include; ease of use (accessibility), versatility and visualization capabilities. However, I would like to discuss some disadvantages of the software as well. The first disadvantage of the software is the learning curve, which is steep. Fortunately, many urban planners and designers are acquainted with designer software, which makes the learning curve more shallow. However, the learning curve decreases the accessibility of the visualizations. The second disadvantage is the rendering time of the visualizations. Producing ten second animations can take up to one hour of rendering time, dependent on the graphical power of the computer. Fortunately, due to technological advancements the rendering time will be reduced in the future.

Methods

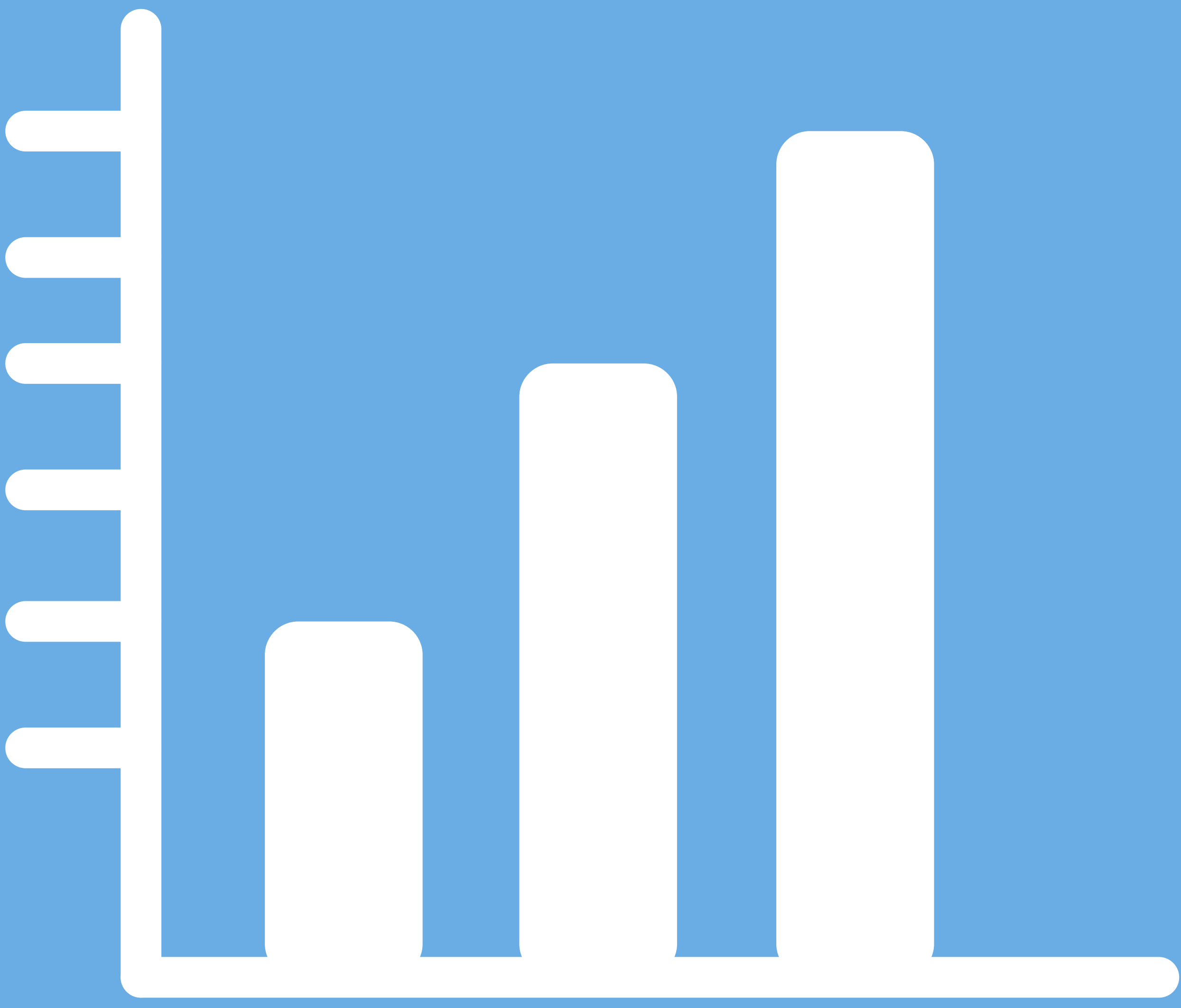
The majority of the research methods appeared to be adequate in relation to the research question(s). The literature study formed a strong scientific basis to develop the design (visualizations). Subsequently the five steps in developing new visualizations (Sheppard, 2012), appeared to be effective in developing new visualizations. This step-by-step guide was easy to follow and included the complete process of developing new visualizations. The survey appeared to be one of the most essential methods during this research. The survey was an important method to build defensibility and quality of the visualizations. Furthermore it was helpful in improving the visualizations. The code of ethics (Sheppard, 2001), provided a solid base in developing assessment criteria for the questionnaire, but should always be considered carefully.

The code of ethics is helpful in increasing validity and reliability of visualizations, but is far from complete. Beyond the choice of medium or software, many factors influence the quality of visualizations such as, content choices, audiences, viewpoints and presentation modes. Therefore, it has to allow for uncertainty and flexibility in rapidly changing technologies and diverse (landscape) products (Bishop & Lange, 2005). The main obstacle during the evaluation, using the code of ethics, was the lack of quantification. The code attempts to provide reasonable and feasible safeguards for reliability, validity and other aspects involving the quality of visualizations, but does not define the definitions of 'reasonable' and 'appropriate' methods (Bishop & Lange, 2005). The code appeared to be useful in creating awareness of visualization validity and reliability, but the lack of quantification made it difficult to draw specific conclusions.

Cavens (2002) suggests two different approaches to safeguard or limit threats to visualization quality: 1. More prescriptive approaches (more detailed and quantified code of ethics), which guide or drive the presentation of visualization material according to established principles or standards; and 2. More flexible and interactive approaches which give much greater control over visualization information to the user/viewer. The prescriptive approach includes a standard format or template to create 'high quality' visualizations and forces visualization preparers to think about validity and reliability issues. This prescriptive approach would work with any visualization tool or software and should be applied when interactive visualizations are unachievable (e.g. due to resource requirements). A flexible and interactive approach will give the viewer much more interactive control over what they see, and freedom to roam within the visualization data set.

Chapter 3

RESULTS



3.1 Version 1.0

The following sections will present the developed new visualizations. First the results of version 1.0 will be presented, which was subsequently reviewed by the participants of the survey and expert meetings. The results of the review were then used to improve the visualizations, which resulted in version 2.0.

After experimenting with the visualization variables, particle characteristics and approximately five expert meetings, version 1.0 of the visualizations was completed. Still frames of the results of version 1.0 are shown in Figure 35. Animations are accessible (with internet connection) by clicking on the play button:

General
In all visualizations, particles of incoming (short-wave radiation) flows are displayed as dots in a line, evenly distributed. Outgoing particles are displayed as dots, randomly distributed. The built-up environment is displayed on the smallest scale possible (25x150m), in which characteristic elements of the LCZ are visible. This scale increased legibility and saved rendering time. Animations show the 3D model in 360 degrees rotation (day-night) and 180 degrees rotation (day). Comparison animations between the local climate zones are accessible in Figure 36 (page 33).

Net all-wave radiation and storage heat
Incoming short-wave radiation, from the sun, is displayed by yellow dots, which are evenly distributed. Short-wave radiation is partly absorbed by the urban materials and transformed into thermal energy (Figure 35, 1.1-1.3).
Long-wave radiation is displayed by red dots, randomly distributed (Figure 35, 2.1-2.3). Long-wave radiation is mainly released during night-time. For example, city centres release more long-wave radiation during the night, because more radiation is stored in this climate zone during the day (Figure 36, 1).
The storage heat is displayed by the coloured ribbon at the bottom of the 3D model (Figure 35, 1.1-2.3). This ribbon corresponds to the temperature of the material. For example, the animation shows that dark materials, such as asphalt, have higher temperatures (red colour) than grass (yellow colour). The temperature difference is also caused by the albedo, emissivity and conductivity of the materials (Lenzholzer, 2013). Furthermore, the city centre stores more heat during the day and releases more heat during the night, compared to the park (Figure 35, 1.1-2.3).

Sensible heat
Sensible heat is displayed by orange dots, which are randomly distributed (Figure 35, 3.1-3.3). Sensible heat is mainly released during daytime. Darker, and thus warmer, materials emit more sensible heat than lighter and thus colder materials. Again, this difference is also caused by the albedo, emissivity and conductivity of the materials. The city centre releases more sensible heat than the park , because city centres contain more hardscape (Figure 36, 2).

Latent heat
Latent heat is displayed by blue dots, randomly distributed (Figure 35, 4.1/4.3). Latent heat is mainly released during daytime, by vegetation and water. The park releases large amounts of latent heat, while the city centre does not release any latent heat, or just small amounts, depending on the vegetation cover. The latent heat visualization of the city centre was omitted in version 1.0, but included in version 2.0 (Figure 43, 12.3).

Anthropogenic heat
Anthropogenic heat is displayed (Figure 35, 5.1/5.2) by purple dots, randomly distributed. Anthropogenic heat is mainly released at daytime, when most human activities take place. At night there is less anthropogenic heat, because human activities will be less. In the visualization, anthropogenic heat is released by buildings and cars. When the LCZ's are compared, it is apparent that the city centre releases the most anthropogenic heat, because most human activities take place in this local climate zone (Figure 36, 4). The park visualization is omitted in version 1.0, but included in version 2.0 (Figure 43, 12.4).

Figure 35: *Results of the visualizations version 1.0 (page 31 and 32)* ⟶

Mixed energy flows

In reality all energy flows occur at the same point in time. This results in a chaotic, but more realistic visualization (Figure 35, 6.1-6.3). When the LCZ's are compared, it does not show more or less particles between the LCZ's, but just a different distribution of energy flows. For example, the park contains high amounts of latent heat, while the city centre contains high amounts of anthropogenic heat (Figure 36, 5).

Wind profile

Due to the building height and width ratio, a variety of wind flows occur around buildings. These wind flows are visualized by arrows (Figure 35, 7.1-7.3). The colour of the arrow indicates the wind velocity. High wind speeds generally occur on the edge of building roofs and façades.

Wind energy

The high wind speeds around roof edges can be used to generate renewable energy (Figure 35, 8.1-8.3). Small wind turbines can be placed here, to extract electricity of wind flows. This extraction is visualized by white dots (electricity). Another option to generate wind energy are pole mounted wind turbines. These wind turbines are especially suited for areas without high buildings (Figure 35, 8.1/8.3).

Solar energy

Incoming solar radiation is displayed by yellow dots (Figure 35, 9.1-9.3). These yellow dots are transformed by photovoltaic cells into electricity (white dots), or to thermal heat by other forms of thermal collectors. Solar collectors can be placed on building roofs (city centre and neighbourhood) or on the ground (park). The generated electricity can be used for buildings, street furniture or can be transported to the electricity grid.

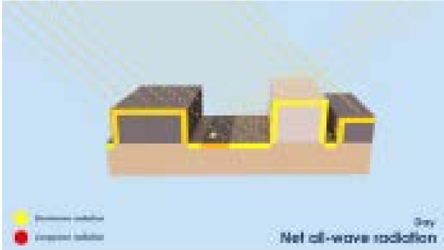
Biomass energy

Biomass energy can be generated from vegetation grown in urban environments. Vegetated areas in urban environments can be parks, but also roofs and façades (Figure 35, 10.1/10.2). In the visualizations vegetation is growing by sunlight (yellow dots), and subsequently harvested and transported to conversion facilities (Figure 35, 10.1-10.3).

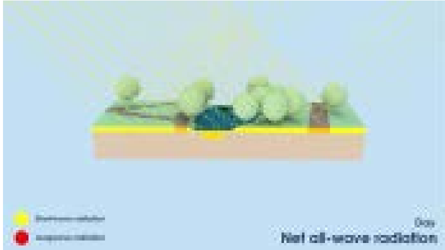
Neighbourhood	City centre	Park

Short-wave radiation

1.1

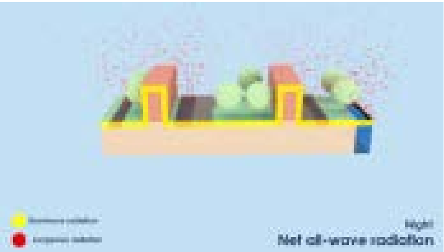


1.2

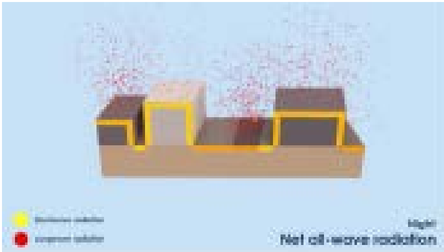


1.3

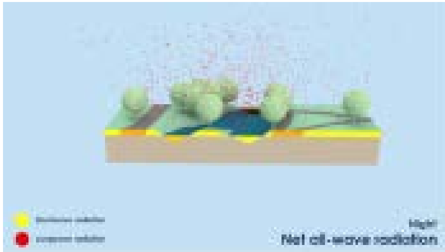
Long-wave radiation



2.1 *See shortwave radiation*

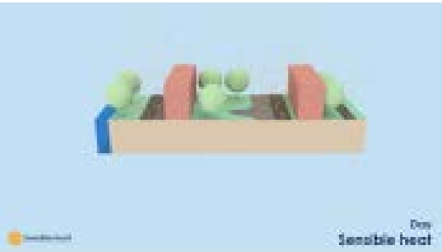


2.2 *See shortwave radiation*

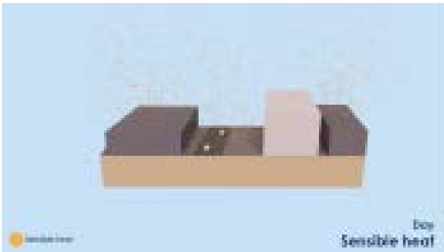


2.3 *See shortwave radiation*

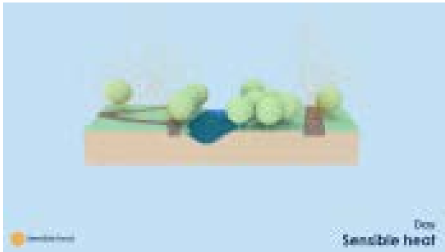
Sensible heat



3.1



3.2



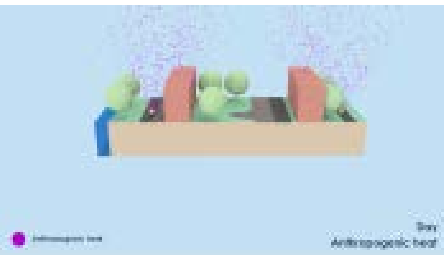
3.3

Latent heat

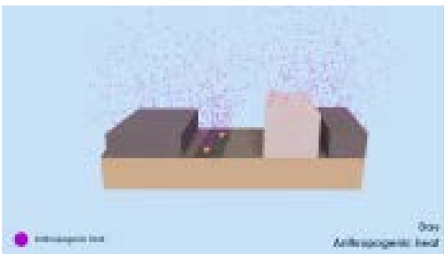
4.1

4.3

Anthropogenic heat



5.1

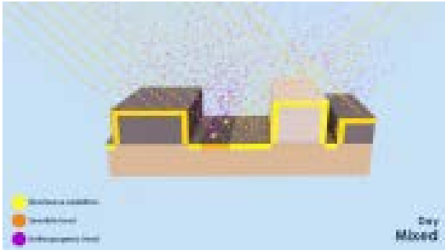


5.2

Neighbourhood | **City centre** | **Park**

Flows mixed

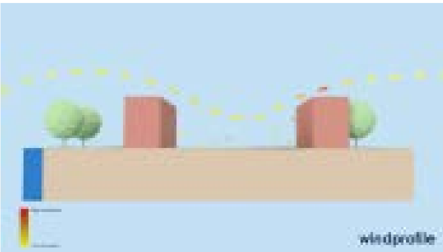
6.1



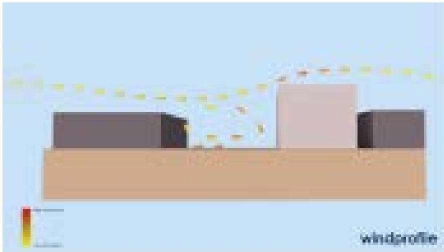
6.2

6.3

Wind profile



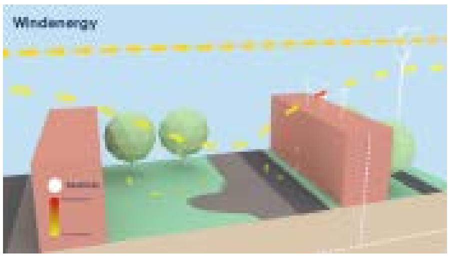
7.1



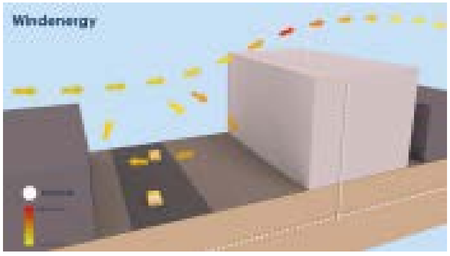
7.2

7.3

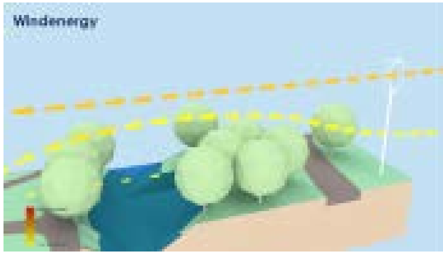
Wind energy



8.1

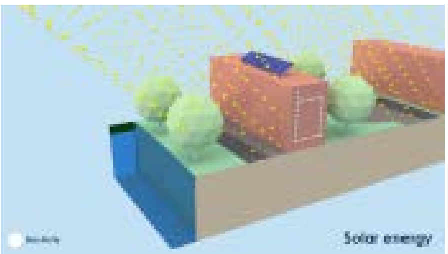


8.2

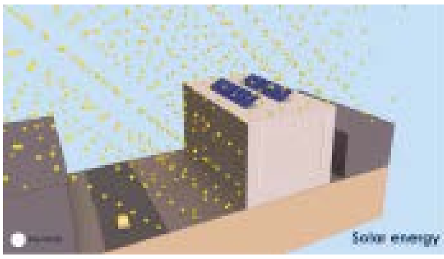


8.3

Solar energy



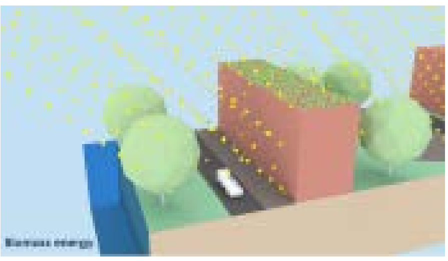
9.1



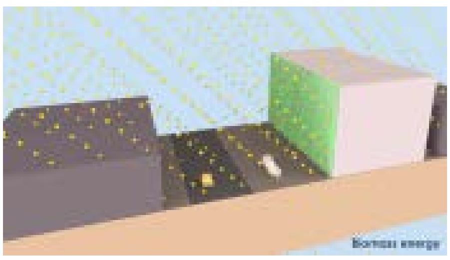
9.2

9.3

Biomass energy



10.1



10.2

10.3

Figure 36: *Comparison animations version 1.0*

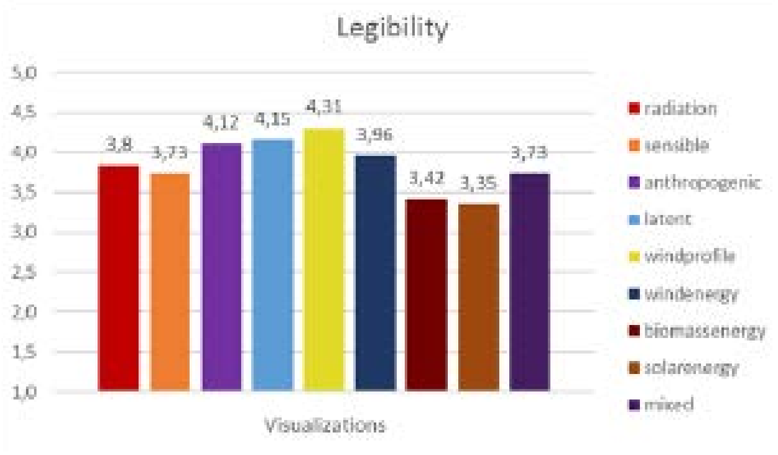


Figure 37: *Mean values of legibility per visualization*

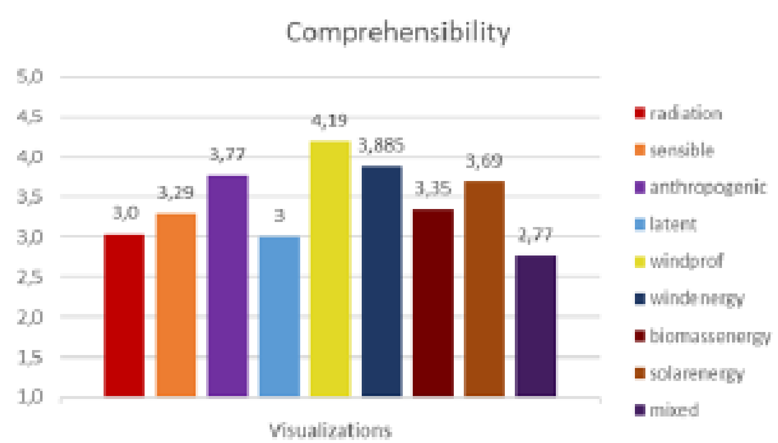


Figure 38: *Mean values of comprehensibility per visualization*

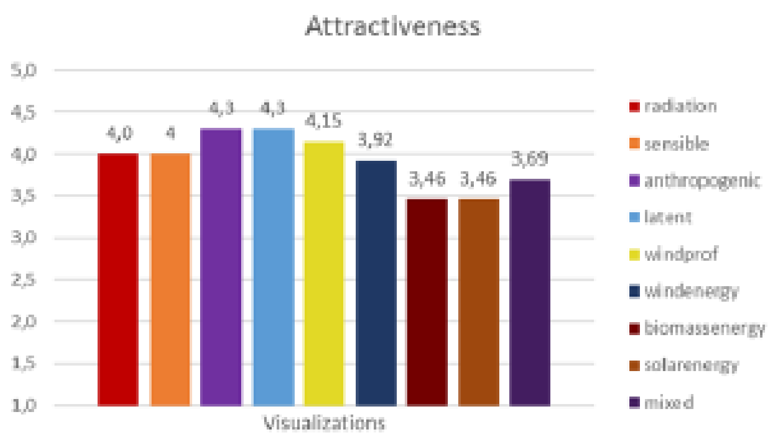


Figure 39: *Mean values of attractiveness per visualization*

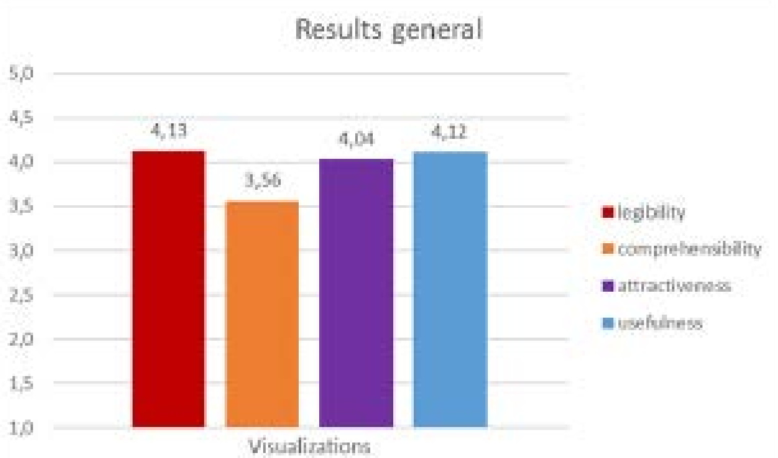


Figure 40: *General mean values of all assessment criteria*

3.1.1 Review of results

Version 1.0 of the visualizations was reviewed by the use of a questionnaire. The results of the questionnaire are shown in Figure 41.

The average score of all the visualizations was ≥3.11. This meant that every questions was agreed upon. Question 3 (Q3), scored the highest (4.46) and question 8 (Q8) scored the lowest (3.11).

Figures 36-38 show the results of the assessment criteria in bar charts for each visualization. Usability was omitted, because the questions about usability only concerned general questions. Figures 36-38 relate to research sub-questions 1-3.

The results of legibility (Figure 37) and attractiveness (Figure 39) showed that the visualizations about climatic energy flows scored higher than the visualizations about renewable energy flows. Comprehensibility (Figure 38) generally scored lower than legibility and attractiveness, especially the visualizations of the net all-wave radiation, latent heat and the mixed flow visualization.

On the three assessment criteria (legibility, comprehensibility, attractiveness), the wind profile visualization scored the highest (total of 12.65, figures 36-38) and the visualization of the mixed energy flows the lowest (total of 10.19, figures 36-38).

Figure 40 shows the results for the assessment criteria of all visualizations together (see Figure 41 for corresponding questions). Comprehensibility clearly showed the lowest value of the assessment criteria.

Assessment area	Metrics	Question	Mean	SD
Legibility	vieuwpoints	Q1: The visual has enough viewpoints	4,20	
	particle amount	Q2: The visual has the right amount of particles	3,49	
	clear components	Q3: The 3D components (buildings, trees etc.)	4,46	0,52
		increase legibility		
	abstraction level	Q4: The visuals have the right abstraction level	4,15	0,8
	animation	Q5: The use of animation increases legibility	4,15	0,55
	colours	Q6: The use of colours enhance clearity	4,38	0,51
Comprehensibility	intuitivity	Q7: The visual is intuitively comprehensible	3,77	
	pre-knowledge	Q8: There is no pre-knowledge is required	3,11	
		to understand the visual		
	particles	Q9: Animated particles show energy flows well	3,62	0,77
	comprehensibility	Q10: The visuals make you understand energy flows	4,08	0,64
		in the microclimate more easily		
	colour transitions	Q11: The colour transition (storage heat) is clear	3,23	1,09
Attractiveness	attractiveness	Q12: The visual is attractive	3,92	
	interest	Q13: The visuals hold your interest	4,15	0,8
Usability	information	Q14: The visuals are informative	4,31	0,48
	useful	Q15: The visuals are useful in future plans & designs	3,96	0,43
	technique	Q16: The used visualization technique is appropriate	4,08	0,28

Figure 41: *Results of the questionnaire version 1.0. From left to right: assessment criterion (column 1), assessment metrics (column 2), questions (column 3), mean result (column 4), standard deviation (column 5, only applicable to specific questions).*

3.1.2 Improvements

Survey

Every participant of the survey could propose improvements to the visualizations. The proposed improvements were considered at a threshold of three similar answers from different participants. Subsequently the proposed improvements of the survey, expert meetings and researcher's observations were incorporated in version 2.0.

Improvement 1: Amount of particles

The first improvement concerned the amount of particles in the visualizations. Multiple participants proposed to show less particles, especially in the renewable energy visualizations, to increase legibility.

In version 2.0 all visualizations contain less and larger particles. The renewable energy visualizations contain less incoming short-wave radiation particles to avoid occlusion.

Improvement 2: Day/night difference

The second improvement concerned the difference between day and night. It was proposed to represent day and night differences more clearly.

In version 2.0 all visualizations contain a clearer distinction between day and night. This was achieved by modifying the colours of the visualizations. Furthermore, all version 2.0 visualizations contain a 24 hour cycle (day/night). This makes it easier to compare the local climate zones.

Improvement 3: Local climate zone difference

The third improvement concerned the differences in particle amounts between the local climate zones. Participants noted that the differences in particle amounts between the local climate zones were not clear.

The differences were made more clear by increased or decreased particle amounts in version 2.0. For example, the difference between long-wave radiation in the city centre was reinforced with more particles and the long-wave radiation in the park with less particles (12.1). This measure increased legibility, but decreased reliability of the visualizations.

Improvement 4: Rotation speed and pauses

The fourth improvement concerned the rotation speed of the animation. Participants noticed that the rotation was distracting in some cases. Furthermore they mentioned that more pauses were preferred.

This improvement was not incorporated in version 2.0, because of: 1. Slowing down the rotation speed would cause more rendering time, because more frames would have to be added to the animation and 2. More pauses are not necessary when the viewer is able to pause the animation at any given time.

'Expert' meetings

At the expert meetings several smaller improvements were proposed to increase the quality of the visualizations. The first improvement concerned the shadows within the 3D model, which were thought to be too light. In version 2.0 all visualizations contain darker shadows, which was achieved by increasing the light emission from the 'sun'. The second improvement concerned the viewing angle of the camera, which was thought to be to high. In version 2.0 of the visualizations the camera viewpoint was lowered five degrees. The third improvement concerned the addition of a time-clock, to indicate the diurnal differences of the energy flows. In version 2.0, this time-clock was added in the top right corner. The fourth and final improvement concerned the addition of raw data as a 2D image. This improvement was added to the city centre visualizations (Figure 42). This data indicates the diurnal amounts of each energy flow. An animated black bar (top left corner) indicates the daytime to the according amount of energy.

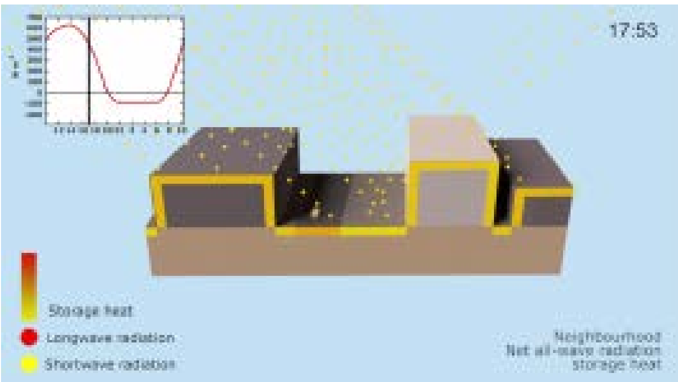
Researcher's observations

Finally I implemented more improvements to the visualizations. The first improvement included an equal camera speed throughout the animation, which would increase legibility. The camera speed in version 1.0 started and ended slow, while the camera speed in version 2.0 contained an equal speed throughout the animation. The second improvement included the use of 2D particles, instead of 3D particles, which reduced rendering times by 30%.

3.2 Version 2.0

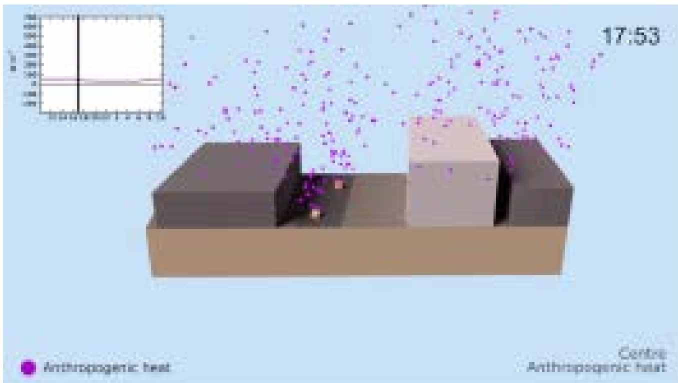
The improved visualizations are shown in Figure 42 and Figure 43 below. The raw data is attached on the top left corner (Grimmond et al, 2004). This measured data is from the city centre of Marseille, France, and gives an indication of the amounts of energy flows within dense urban environment and should therefore not be mistaken with the real-life situation. Figure 43, shows the comparisons of the LCZ's of version 2.0.

Net all-wave radiation



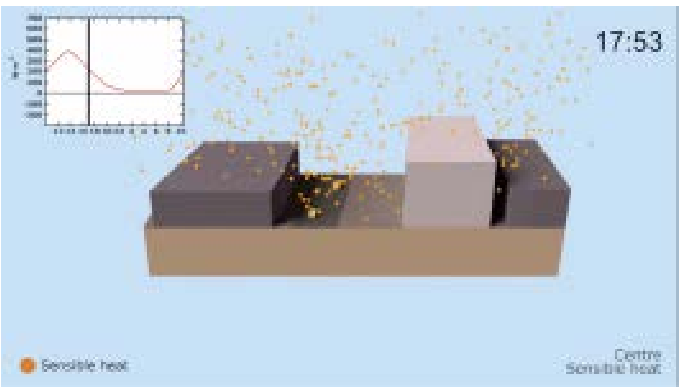
11.1

Anthropogenic heat



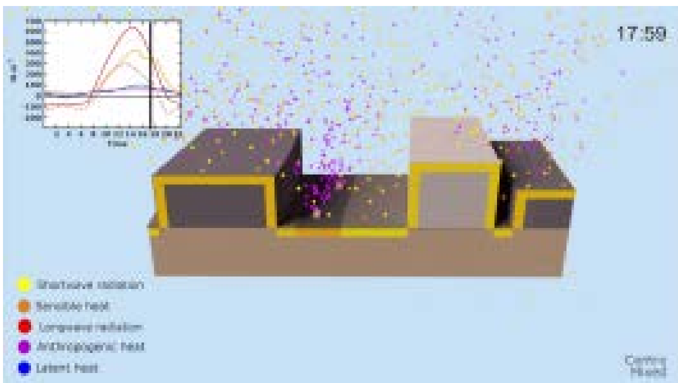
11.2

Sensible heat



11.3

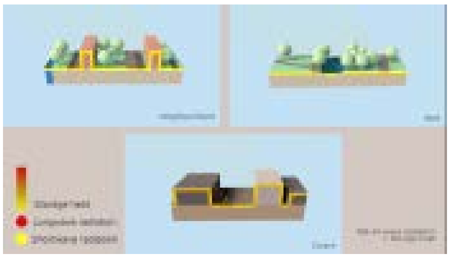
Flows mixed



11.4

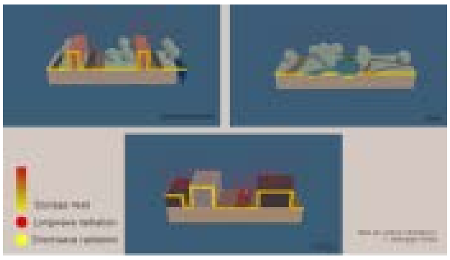
Figure 42: *Version 2.0 city centre*

Short-wave radiation



12.0

Long-wave radiation

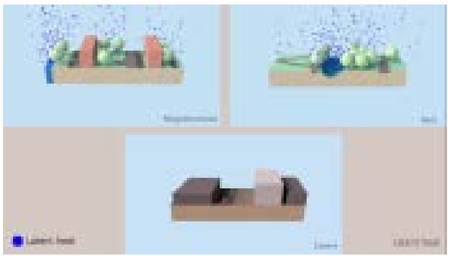


12.1

Sensible heat

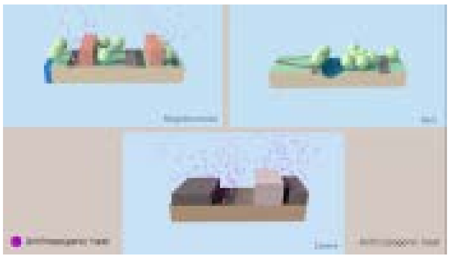
12.2

Latent heat



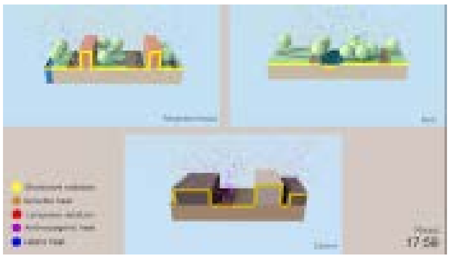
12.3

Anthropogenic heat



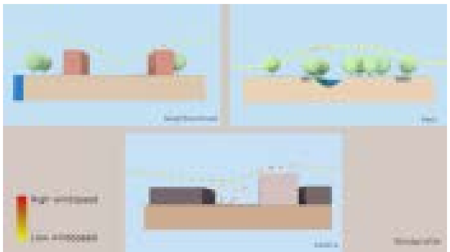
12.4

Mixed flows



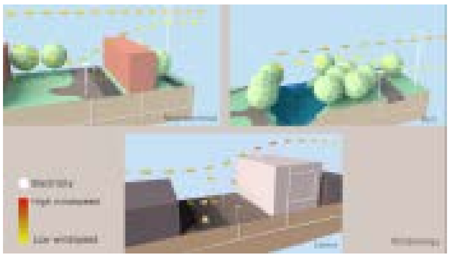
12.5

Wind profile



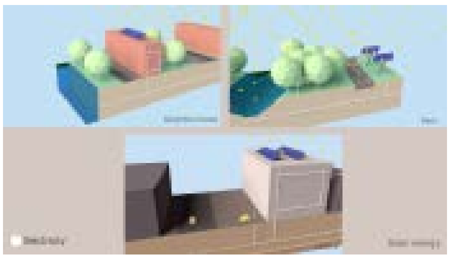
12.6

Wind energy



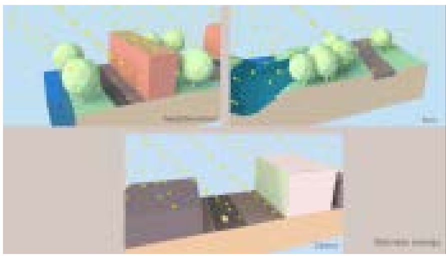
12.7

Solar energy



12.8

Biomass energy



12.9

Figure 43: *Comparisons LCZ's version 2.0*

Chapter 4

DISCUSSION

4.1 Discussion

In this chapter the research questions will be answered and discussed. Furthermore, the scientific and societal impact and future directions will be discussed.

Research question [RQ.1]: What type of visualization can make energy flows (microclimatic and renewable) intelligible for urban planners and designers?

In this study, energy flows in urban microclimates were made intelligible by the use of a new visualization method. This new method was developed by combining visualization techniques, grounded in several research disciplines. Animated 3D visualizations, with the use of particle systems, are the most adequate in representing dynamic urban energy flows. The survey revealed that by using animated 3D visualizations, urban planners and designers were able to comprehend the urban environment in terms of (renewable) energy flows. Comprehension of the energy flows was achieved by the right levels of abstraction, dimensionality and (semi-)interactivity.

Version 1.0 of the visualizations was reviewed quantitatively, which resulted in reliable and valid conclusions. Although the sample size of the survey was relatively small, the results are promising. This is supported by the fact that every question of the questionnaire was agreed upon (≥3.11). The results of the questionnaire indicated that the visualizations involving energy flows, were generally rated higher than the visualizations involving renewable energy flows. This may have been caused due to occlusion and cluttering issues. These issues were probably caused by the amount of particles, which resulted in dazzling the viewer. This corresponds to the literature about (energy) flow visualization, where occlusion and cluttering have always been major challenges (Brambilla et al, 2012), especially with direct flow visualization (McLoughlin et al, 2010). Participants of the survey suggested to display less particles in the visualizations to avoid occlusion. This suggestion was incorporated in version 2.0 of the visualizations.

Sub-question [SQ.1] Are the new visualizations legible?

In the general assessment of the survey, legibility was rated the highest (4.13) of all four assessment criteria. From this score, we can conclude that the visualizations were legible. The most important factors of legibility, were the use of 3D components, colours and by showing enough viewpoints in the visualizations. In the specific assessment criteria of the survey, the results of legibility show a duality between the energy flow visualizations and the renewable energy flow visualizations. This duality may have been caused by occlusion and cluttering issues, because too much particles occluded the view in the renewable energy visualizations.

Sub-question [SQ.2] Are the new visualizations comprehensible?

In the general assessment, comprehensibility was rated the lowest (3.56). This may have been caused by the necessity of pre-knowledge. This is strengthened by the fact that the question regarding pre-knowledge was rated the lowest of all questions, with a score of 3.11. This finding is supported by earlier studies that implicated that visualizations where pre-knowledge was not required were rated higher than visualizations where pre-knowledge was required (Shamim, 2015). The results of the specific assessment criterion comprehensibility, show a wide distribution. The specific cause of this distribution remains unclear, but may have been caused by unclear explanations during the survey (written and/or verbally).

Sub-question [SQ.3] Are the new visualizations attractive?

In the general assessment, attractiveness was rated generally high (4.04). This means that the visualizations are generally attractive and hold the interest of the viewer. The results of the specific assessment, more or less correspond to the results of legibility, and low scores are therefore probably caused by occlusion and cluttering issues as well.

Sub-question [SQ.4] Are the new visualizations useful for (urban) planners and designers?

In the general assessment, usability was rated high (4.12). This result was mainly caused by the high scores of question 14, which involved the amount of information the visualizations were able to transfer to the viewer. This means that the visualizations in general were informative. Question 15, regarding the usability of the visualizations in future plans and design, was rated relatively high as well. Unfortunately, the question does not state if the visualizations are useful as a communication tool or as a design tool. This unclarity may have caused unreliable results. This means that the usability of the visualizations, specifically as a communication tool has not been proven. Finally, the used visualization technique was thought to be appropriate in representing urban energy flows. Accessibility plays an important role in the use of these visualizations. Due to the complex work flow in creating the visualizations, accessibility decreases and the visualizations can be generally considered to fall within the expert domain. And even for domain experts, extensive tutorials may have to be provided to replicate the visualizations.

Transferring urban climate knowledge to routine planning and design practice seems to be a major challenge (Mills, 2014). This research bridges the gap between knowledge (urban climatology) and practice (urban planning and design), by using a new visual communication method. By using this new method, urban planners and designers will be able to comprehend the complex interactions of energy in urban environments and how these interactions can be used to improve the environmental performance of the urban landscape in an accessible and applicable manner. Furthermore, these visualizations will help them to improve the overall sustainability of urban environments, by reducing urban heat, improving the living environment, and exploring the potential implementation of renewable energy generation. This will directly benefit the society as a whole.

The development of this new visualization method is one of the first steps in communicating urban energy systems to mainstream planning and design.
The next step will be to develop the visualizations as a tool for design. However, to make the visualizations widely accessible as a design tool, I suggest to make the visualizations more interactive. This requires close collaboration between (urban) designers, (urban) climatologists and computer scientists. Urban designers could focus on the visual aspects, while urban climatologists can focus on the data, and computer scientists on the technical aspects of the model. Providing more choice and freedom would reduce the risk of systematic bias from the presenter or preparer, and allows more direct and individualized estimates of validity and reliability (Bishop & Lange, 2005). In a more interactive environment viewers would be able to import their own plan or design and decide which energy flow(s) they want to examine. Further improvements in interactivity would involve the option to add or remove certain elements of the design. For example by adding trees, latent heat will be increased and urban temperatures may decrease. In an ideal situation the planner or designer would be able to add more trees until the environment would be comfortable to live in. This would create a more simulated environment, similar to ENVI-met (climatological simulation software), but would be much more accessible and comprehensible.

Another option would be to involve virtual- or augmented reality techniques in combination with measuring instruments, for example to examine real-life energy flows. These types of realities may increase immersion, but like interactive models, require many resources. In the end trade-offs will always have to be made between utility, feasibility and cost implications. Moreover, there is nothing to say that self-choice would automatically lead to the appropriate information being found or seen, and could even lead to more biased and confusing arrays of visualization. Some combination of prescriptive and interactive approaches might lead to the greatest validity, while preserving freedom to explore the visualization process and design options (Bishop & Lange, 2005).

This research provides a basis for widely accessible and applicable tools for communicating energy systems to (urban) planning and design. The visualization method of this research will help (urban) planners and designers to improve the overall sustainability of urban environments, by reducing urban heat, improving the living environment, and exploring the potential implementation of renewable energy generation.

Literature

Abdelalim, A., et al. (2015) Visualization of energyW and water consumption and GHG emissions: A case study of a Canadian University Campus. Energy and Buildings, 109, 334-352.

Akbari, H. (2002) Shade trees reduce building energy use and CO2 emissions from power plants. Environmental pollution, 116, S119-S126.

Alemasoom, H., et al. (2016) EnergyViz: an interactive system for visualization of energy systems. The Visual Computer, 32.3, 403-413.

Allegrini, J., et al. (2015) A review of modelling approaches and tools for the simulation of district-scale energy systems. Renewable and sustainable energy reviews, volume 52, 1391-1404.

Appleton, K., et al. (2002) Rural landscape visualization from GIS databases: A comparison of approaches, options and problems. Computers, Environment and Urban Systems, 26, 141–162.

Arnfield, A. J. (2003). Two decades of urban climate research: a review of turbulence exchanges of energy and water, and the urban heat island. International Journal of Climatology, 23, 1–26.

Bäckström, E. (2006) The surface energy balance and climate in an urban park and its surroundings. Thesis, Uppsala, Sweden.

Bishop, I.D., Lange, E. (2005) Visualization in landscape and environmental Planning: Technology and Applications. Taylor & Francis, London.

Brambilla, A., et al. (2012) Illustrative flow visualization: State of the art, trends and challenges. Visibility-oriented Visualization Design for Flow Illustration.

Bruce, V., Green, P.R. and Georgeson, M.A. (1996) Visual perception, physiology, psychology and & ecology. Psychology Press, 2003.

Brugmans, G., Strien, J. (2014) 'Urban by nature'. IABR, Rotterdam.

Cavens, D. (2002) A design-based decision support system for forest design. Unpublished MSc.
thesis, University of British Columbia, Vancouver, BC.

Christen, A., Vogt, R. (2004) Energy and radiation balance of a Central European City. International Journal of Climatology, 24, 1395–1421.

Downes, M., Lange E. (2015) What you see is not always what you get: A qualitative, comparative analysis of ex ante visualizations with ex post photography of landscape and architectural projects. Landscape and Urban Planning, 142, 136-146.

Dudarev, I., et al. (2013) Visualization of Energy Flows Using a Particle System. Mechatronics 2013, Springer International Publishing, 185-192.

Erell, E., Pearlmutter, D., Williamson, T. (2011) Urban microclimate: Designing the spaces between buildings'. Routledge, Abingdon.

Grimmond, C.S.B., et al. (2004) Flux and turbulence measurements at a dense urban site in Marseille: heat, mass (water, carbon dioxide) and momentum. Journal of Geophysical Research: Atmosphere, 109, 19.

Grimmond, C.S.B., et al. (2010) Climate and more sustainable cities: climate information for improved planning and management of cities. Environmental Sciences: Processes, 1, 247–274.

Häb, K. (2015) Visualization and analysis techniques for urban microclimate data sets. Dissertation, Technical University Kaiserslautern, Kaiserslauterns.

Hauser, H. et al. (2003) The State of the Art in Flow visualization, part 1: Direct, Texture-based and Geometric Techniques." Proceedings IEEE Visualization.

Heath, M.A., et al. (2007) Estimating the Potential Yield of Small Building-mounted Wind Turbines. Wind Energy, 10, 271–287.

Hebbert, M. and Mackillop, F. (2013) Urban climatology applied to urban planning: a post-war knowledge circulation failure. International Journal Urban Regeneration, 37, 1542–1558.

Honjo, T, Takakura, T. (1990) Simulation of thermal effects of urban green areas on their surrounding areas. Energy and Buildings, 15.3-4, 443-446.

Inam, A. (2013) Designing urban transformation. Routledge, New York.

Ishugah, T.F., et al. (2014) Advances in wind energy resource exploitation in urban environment: A review. Renewable and Sustainable Energy Reviews, 37, 613–626.

Kanters, J., Horvat, M. (2012) Solar energy as a design parameter in urban planning. Energy Procedia 30, 1143 – 1152.

Keirstead, J., Jennings, M., Sivakumar, A. (2012) A review of urban energy system models: Approaches challenges and opportunities'. Renewable and sustainable energy reviews, 16, 3847-3866.

Keirstead, J., Shah, N. (2013) Urban energy systems: An integrated approach. Routledge, Abingdon.

Kennedy, C. (2010) The study of urban metabolism and its applications to urban planning and design. Environmental pollution, 159, 1965-1973.

Kennedy, C., Cuddihy, J., and Engel-Yan, J. (2007) The changing metabolism of cities. Journal of industrial ecology, 11.2, 43-59.

Kotthaus, S., Grimmond, C.S.B (2014) Energy exchange in a dense urban environment – Part I: Temporal variability of long-term observations in central London. Urban Climate, 10, 261–280.

Lenzholzer, S. (2013) Het weer in de stad. Hoe ontwerp het stadsklimaat bepaalt, Rotterdam, Nai010 uitgevers.

Lenzholzer, S., Duchhart, I., and Koh, J. (2013) Research through designing in landscape architecture. Landscape and Urban Planning, 113, 120-127.

Li, D. Liu, G., Liao, S. (2015) Solar potential in urban residential buildings. Solar Energy 111, 225–235.

Liang, Z., Zhou, H. (2009) Three-dimension Fountain Simulation Based on GPU and Particle system. International Forum on Information Technology and Applications, 37–39.

Lovett, A., et al. (2015) Using 3D visualization methods in landscape planning: An evaluation of options and practical issues. Landscape and Urban Planning, 142, 85-94.

MacEachren, A.M., et al. (1999) Virtual environments for geographic visualisation: potential and challenges. ACM Workshop on New Paradigms for Information Visualization and manipulation, Kansas City, 35-40.

Macleod, A. (2008) Using the microclimate to optimise renewable energy installations. Renewable Energy, 33, 1804–1813.

Masson, V., Grimmond, C. S. B., and Oke, T. R. (2002). Evaluation of the town energy balance (TEB) scheme with direct measurements from dry districts in two cities. Journal of Applied Meteorology, 41(10), 1011–1026.

McCormick, B. H., T. A. DeFanti, and M. D. Brown (1987) Visualization in scientific computing. Computer Graphics, 21, (entire issue).

McLoughlin, T., et al. (2010) Over two decades of integration-based, geometric flow visualization. Computer Graphics Forum 29, 6, 1807–1829.

Mertens, E. (2010) Visualizing landscape architecture. part of Springer Science + Business media, Basel.

Mills, G. (2014) Urban climatology: History, status and prospects. Urban Climate, 10, 479-489.

Mills, G., et al (2010) Climate information for improved planning and management of mega cities. Procedia Environmental Sciences, 1, 228–246.

Mohajeri, N., et al. (2016) Effects of urban compactness on solar energy potential. Renewable Energy, 93 , 469-482.

Nocke, T., et al. (2007) Visual exploration and evaluation of climate-related simulation data. Winter Simulation Conference, IEEE.

OECD, IEA (2015) Key world energy statistics. Chirat, France.

Offenhuber, D. (2010) Visual anecdote. Leonardo 43.4, 367-374.

Offermann, R., et al. (2011) Assessment of global bioenergy potentials. Mitigation and Adaptation Strategies for Global Change, 16.1, 103-115.

Oke, T. R. (1982) The energetic basis of the urban heat island. Quarterly Journal of the Royal Meteorological Society, 108, 1–24.

Oke, T.R. (1984) Towards a prescription for the greater use of climatic principles in settlement planning. Energy and Buildings, 7, 1-10.

Pearlmutter, D., Berliner, P (2004) Evaluation of Urban Surface Energy Fluxes Using an Open-Air Scale Model. Journal of applied meteorology, 44, 532-545.

Post, F.H., et al. (2002) Feature extraction and visualization of flow fields. Eurographics 2002 State-of-the-Art Reports 1, 69-100.

Rasheed, A. (2009) Multiscale modelling of urban climate. Ph.D Thesis, 4531, EPFL, Lausanne, Switzerland.

Robitu, M., et al. (2006) Modeling the influence of vegetation and water pond on urban microclimate. Solar Energy, 80.4, 435-447.

Schmidt, M. (2008) The Sankey Diagram in Energy and Material Flow Management Part I: History, Journal of industrial ecology, 12, 82-94.

Shahrestani, M., et al. (2015) A field study of urban microclimates in London. Renewable Energy, 73, 3-9.

Sheppard, S.R.J. (1989) Visual simulation: A user's guide for architects, engineers, and planners. Van Nostrand Reinhold, New York.

Sheppard, S.R.J. (2001) Guidance for crystal ball gazers: developing a code of ethics for landscape visualization. Landscape and Urban Planning, 54:183–199.

Sheppard, S.R.J. (2012) Visualizing climate change: a guide to visual communication of climate change and developing local solutions, Routledge, Abingdon.

Simpson, J. R. (2002) Improved estimates of tree-shade effects on residential energy use. Energy and Buildings, 34.10, 1067-1076.

Slocum, T.A., et al. (2001) Cognitive and usability issues in geo-visualization. Cartography and Geographic Information Science, Volume 28, 61–75.

Stewart, I.D., and Oke, T.R. (2012) Local climate zones for urban temperature studies. Bulletin of the American Meteorological Society, 93.12, 1879-1900.

Svakhine, N.A., et al. (2005) Illustration and photography inspired visualization of flows and volumes. VIS 05, IEEE Visualization.

Turkbeyler, E., et al. (2011) Urban microclimates and renewable energy use in cities. World renewable energy congress 2011, Sweden.

Vallati, A., et al. (2015) On the Impact of Urban Micro Climate on the Energy Consumption of Buildings. Energy Procedia, 82, 506-511.

Wolman, A. (1965) The metabolism of cities. Scientific American, 213 (3), 179-190.

Yau, N. (2013) Data points: Visualization that means something. John Wiley & Sons, Inc., Indianapolis, Indiana.

Zeman, F. (2012) Metropolitan sustainability: Understanding and improving the urban environment. Woodhead Publishing Limited, UK.

Zhou, S. et al. (2006) Fire model based on Particle system and its application in Virtual Reality. Processing of the 16th International Conference on Artificial Reality and Telexestence-Workshop, ICAT.

List of figures

Figure 2: Mills, G. (2014) Urban climatology: History, status and prospects. Urban Climate, 10, 479-489.

Figure 4: Grimmond, C.S.B., et al. (2004) Flux and turbulence measurements at a dense urban site in Marseille: heat, mass (water, carbon dioxide) and momentum. Journal of Geophysical Research: Atmosphere, 109, 19.

Figure 5: Kotthaus, S., Grimmond, C.S.B (2014) Energy exchange in a dense urban environment – Part I: Temporal variability of long-term observations in central London. Urban Climate, 10, 261–280.

Figure 6: Kennedy, D., (2007) Cleveland is a More Beautiful City than You Remember [Image online], available: https://danakennedy.wordpress.com/2009/10/01/cleveland-is-a-more-beautiful-city-than-you-remember/cleveland-june-30-2007-052/ [accessed 10 Nov 2016]

Figure 7: Mahan, S., (2014) 40 Religious Groups Practicing Creation Care with Wind Turbines [Image online], available: http://blog.cleanenergy.org/2014/02/23/creationcare/ [accessed 10 Nov 2016]

Figure 8: AMA REINFORCEMENT (2015) Bahrain world trade centre [Image online], available: http://steel.amabuildingmaterials.com/completed-projects.html [accessed 10 Nov 2016]

Figure 9: ZME Science (2016) No title [Image online], available: http://www.zmescience.com/ecology/renewable-energy-ecology/solar-panels-pros-and-cons-056654/ [accessed 10 Nov 2016]

Figure 10: HowStuffWorks (2016) No title [Image online], available: http://science.howstuffworks.com/environmental/green-science-pictures.htm [accessed 10 Nov 2016]

Figure 11: Pedd, J., (2016) No title [Image online], available: https://www.techzine.nl/nieuws/99343/tesla-en-solarcity-lanceren-speciaal-zonnedak.html [accessed 10 Nov 2016]

Figure 12: Landezine (2015) No title [Image online], available: http://www.landezine.com/index.php/2011/02/shanghai-houtan-park-by-turenscape/43-turenscape-landscape-architecture-houtan-park/ [accessed 10 Nov 2016]

Figure 13: ViralPosme (2014) Universidad del Claustro de Sor Juana en México [Image online], available: http://viralposme.com/algunos-de-los-jardines-sin-horizonte-tienes-nada-mas-que-verlos/ [accessed 10 Nov 2016]

Figure 14: Hayward, A., (2016) Pop-up shops will have the OnePlus 3 for sale on 15 June [Image online], available: http://www.stuff.tv/news/pop-shops-will-have-oneplus-3-sale-15-june [accessed 10 Nov 2016]

Figure 15: Thorpe, J., (2009) No title [Image online], available: http://quod.lib.umich.edu/j/jep/3336451.0014.212?view=text;rgn=main [accessed 10 Nov 2016]

Figure 16: Archenhancer, V., (2014) Duplex_Villa [Image online], available: http://www.cgarchitect.com/2014/02/duplexvilla [accessed 10 Nov 2016]

Figure 17: Shark, D., (2009) Graphical projection comparison [Image online], available: https://commons.wikimedia.org/w/index.php?curid=8497328 [accessed 10 Nov 2016]

Figure 18: Baez, J.C., (2013) Symmetry and the Fourth Dimension [Image online], available: https://johncarlosbaez.wordpress.com/2013/06/04/symmetry-and-the-fourth-dimension-part-10/ [accessed 10 Nov 2016]

Figure 19: Mertens, E. (2010) Visualizing landscape architecture. part of Springer Science + Business media, Basel.

Figure 20: Lovett, A., et al. (2015) Using 3D visualization methods in landscape planning: An evaluation of options and practical issues. Landscape and Urban Planning, 142, 85-94.

Figure 21: Unknown author [Image online], available: https://i.ytimg.com/vi/Fc87s7lA3jM/maxresdefault.jpg [accessed 10 Nov 2016]

Figure 22: Hauser, H. et al. (2003) The State of the Art in Flow visualization, part 1: Direct, Texture-based and Geometric Techniques." Proceedings IEEE Visualization.

Figure 23: Oke, T. R. (1988) Street design and urban canopy layer climate. Energy and buildings 11.1 , 103-113.

Figure 24: Nocke, T., et al. (2007) Visual exploration and evaluation of climate-related simulation data. Winter Simulation Conference, IEEE.

Figure 25: Soundararajan, K, et al. (2014) Sankey diagram framework for energy and exergy flows. Applied energy, 136, 1035-1042.

Figure 26: Kennedy, C. (2010) The study of urban metabolism and its applications to urban planning and design. Environmental pollution, 159, 1965-1973.

Figure 27: Kennedy, C. (2010) The study of urban metabolism and its applications to urban planning and design. Environmental pollution, 159, 1965-1973.

Figure 28: Krüger, J., et al (2005) A Particle System for Interactive Visualization of 3D Flows, IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS, VOL. 11, NO. 6, 11.

Unmentioned figures are made by the author of this Thesis report

Appendix

Appendix 1: Interim code of ethics for (landscape) visualization (Sheppard, 2001)

Purpose of landscape visualization

Professional preparers and presenters of landscape visualizations are responsible for promoting full understanding of proposed landscape changes; providing an honest and neutral visual representation of the expected landscape, by seeking to avoid bias in responses (as compared with responses to the actual project); and demonstrating the legitimacy of the visualization process

General principles

Preparers and presenters of landscape visualizations will adhere to the following general principles

Accuracy: realistic visualizations should simulate the actual or expected appearance of the landscape as closely as possible (at least for those aspects of the landscape being considered)

Representativeness: visualizations should represent the typical or important range of views, conditions, and time-frames in the landscape which would be experienced with the actual project, and provide viewers with choice of viewing conditions

Visual clarity: the details, components, and overall content of the visualization should be clearly communicated

Interest: the visualization should engage and hold the interest of the audience, without seeking to entertain or "dazzle" the audience

Legitimacy: the visualization should be defensible through making the simulation process and assumptions transparent to the viewer, and by clearly describing the expected level of accuracy and uncertainty

Access: to visual information: visualizations which are consistent with the above principles should be made readily accessible to the public via a variety of formats and communication channels

Code of ethical conduct

The use of landscape visualizations should be appropriate to the stage of development of project under consideration, to the landscape being shown, to the types of decisions being made, to the audience observing the visualizations, to the setting in which the presentation is being made, and to the experience level of the preparer. Within this context, preparers and presenters of landscape visualization will:

Demonstrate an appropriate level of qualifications and experience

Use the appropriate visualization system(s) and media for the purpose

Choose the appropriate level of realism

Identify, collect, and document supporting visual data available for or used in the visualization process; conduct an on-site visual analysis to determine important issues and views

Seek community input on viewpoints and landscape issues to address in the visualizations

Estimate and disclose the expected degree of error and uncertainty

Use more than one appropriate presentation mode and means of access for the affected public

Provide the viewer with a reasonable choice of viewpoints, view directions, view angles, viewing conditions, and timeframes appropriate to the area being visualized

Present important non-visual information at the same time as the visual presentation

Avoid the use or the appearance of "sales" techniques or special effects

Avoid seeking a particular response from the audience

Provide information describing how the visualization process was conducted and key assumptions/decisions taken

Record responses to visualizations as feedback for future efforts

Conduct post-construction evaluations to document accuracy of visualizations or changes in project design/construction/use

Appendix 2: Local Climate Zone (LCZ) map of Amsterdam (