THE IMPACT OF GREEN WALLS AND ROOFS TO URBAN MICROCLIMATE IN DOWNTOWN DALLAS, TEXAS: LEARNING FROM SIMULATED ENVIRONMENTS

by

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Presented to the Faculty of the Graduate School of
The University of Texas at Arlington in Partial Fulfillment
of the Requirements
for the Degree of

MASTER IN LANDSCAPE ARCHITECTURE

THE UNIVERSITY OF TEXAS AT ARLINGTON
December 2013

Acknowledgements

I would like to express my sincere appreciation to my committee chair Dr. Taner R. Ozdil, who guided me and supported me through not only my research but the program of landscape architecture. Thank you for encouraging me to always do my best.

I would like to thank my committee members, Professor John McDermott, for sharing his knowledge simulating natural environments and architecture. Dr. Pat D. Taylor for believing in me and giving me the opportunity to be in the program; and Professor James Richards who brought back my passion for drawing and who taught me so much in a short period of time. Additionally, I would like to thank Professor David Hopman for his teaching and for supervising while being his GRA for a year; Professor John Fain for believing in me and pushing me to learn more and never give up. Thank you to all the faculty and adjunct professors for sharing their knowledge and giving the best of them. A special thanks to Charles Schneider, Russell Southard and Thinh Vo for helping me with the environmental simulation studies. To my friends and colleagues, thank you for all the time we have spent together. I will cherish those moments in my heart. Thank you, Dorothy, for all the editing, and to you and Xie for your unconditional friendship.

To my parents, Lazaro and Rebeca, thank you for always believing in me and encouraging me to be a better person every day and to do my best. Without them, I would not have been able to become who I am today. To Mauricio, Shaina and Oren, and Annette, Sammy and Yael, thank you for your support, for the calls and comforting words, thank you for making my days better and always making me smile. My deepest gratitude goes to Carlos, my husband, who supported me and encouraged me to pursue my dream, thank you for always bringing joy and love into my life, I am back.

November 22, 2013

Abstract

THE IMPACT OF GREEN WALLS AND ROOFS TO URBAN MICROCLIMATE IN DOWNTOWN DALLAS, TEXAS: LEARNING FROM SIMULATED ENVIRONMENTS

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Microclimate refers to a localized zone where the climate is different than the surrounding area. In dense urban areas, climate is affected by “urban thermo-physical and geometrical characteristics, anthropogenic activities and heat sources” (Dimoudi et.al. 2013, p.1). Materials such as brick, asphalt, and concrete absorb the sun’s energy, and then heat-up, and re-radiate that heat into the ambient air, creating urban heat island effects. These effects can be partially mitigated by modifying the physical surface and mass properties of buildings. By adding vegetation and soil, in addition to the shade made by surrounding buildings, seasonal energy gain may be modified.

Green walls and roofs help reduced urban heat island effects, improve air quality, and storm-water runoff (Greenscreen, 2012; Cantor, 2008). According to the National Weather Service, Dallas, Texas has an average high winter temperature of sixty-one degrees Fahrenheit and, an average high summer temperature of ninety-six degrees Fahrenheit (NOAA, 2012; Winguth and Kelp, 2013). Studies indicate that the urban heat island effect can increase the temperature six to eight degrees Fahrenheit (HARC and EPA, 2009) and generate a warmer microclimate in the downtown area. The

Leadership in Energy and Environmental Design (LEED) encourages the use of green walls and roof systems to reduce microclimates generated by infrastructures and buildings (USBG, 2013). Although there are a few buildings in the Downtown Dallas area that have employed green façades and roofs, little is known about the impact of green façades and roofs on microclimate.

The purpose of this research is to study the impact of green walls and roofs on urban heat island effect in urban areas. This research studies downtown microclimate and uses downtown Dallas, Texas, models as a lab to test and illustrate the potential of green walls and roofs on urban heat island effects. The research specifically focuses on seasonal wind patterns and solar exposure simulations at various scales, from a single building to a district, to understand and visualize such impacts.

This study focuses on the impact of green walls and roofs in a section of the central business district of Dallas, Texas. It studies locations to understand the effects of green walls and roofs aimed by simulated experiments. Two physical models were made to simulate a portion of Downtown Dallas. Sun and air movement studies were conducted on the models. Water Tank, Shallow Water Table, and Heliodon experimental techniques were used to study and visualize a range of scenarios (McDermott et al., 2013). Outcomes are documented photographically and data are compared through the photographs with the before and after scenarios.

Wind and sun studies in simulated environments show that, when placing green walls and roofs, buildings are protected and the effects of the wind and sun radiation are lessened. Simulations also suggest the application and appropriate placement of features like green walls and roofs can influence microclimate and help reduce the urban heat island effects in the case of Dallas, Texas.

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Chapter 1

Introduction

1.1 Introduction

The urban microclimate is affected by the conditions of the built environment. The main factors that affect microclimate are: topography, sun angle exposure, latitude, soil type, and vegetative cover. The urban heat island effect is the main type of microclimate seen in urban areas (Kleerekoper et al., 2012). Urban areas are usually warmer than rural areas because urban areas tend to have more impervious surfaces such as buildings, roads, and parking lots (Winguth and Kelp, 2013). The use of green walls and green roofs can help alleviate the impact of existing or new buildings. They promote biomass to cool urban areas, support the growth of tree canopies, improve air quality, and mitigate stormwater runoff (Greenscreen, 2012).

Green walls and green roofs are vertical or horizontal green infrastructures that can help reduce the urban heat island effect because of the placement on the buildings and the green coverage that they provide. They can reduce the outside temperature of a building as well as the inside. “According to the Environmental Protection Agency (EPA), trees and vegetation lower surface and air temperatures by providing shade, and through evapotranspiration” (Greenscreen, 2012, p.3). The heat exchanges between the grass foliage and the air are milder than those between the solid concrete roof and the air. The total radiative heat flux density (both short and long wave radiation) on the external surface of the concrete roof is also larger than that on the upper part of the canopy layer. Plants function as a solar filter and they prevent the absorption of heat radiation into the materials of the building (Perini et al., 2011). Green walls provide a cooling system to the buildings; green roofs obtain air masses that enter the canyon cooler. Both systems absorb the convective, conductive, evaporative and radiative heat fluxes through their vegetation allowing the temperature on concrete roofs or walls to differ significantly (Alexandri et al., 2006).

Urban surfaces, such as the building envelope (walls and roofs), can be covered with vegetation to alter the microclimate of the built environment, as well as the local climate of the city. The magnitude of temperature decreases due to this transformation depends on the climatic characteristics, the amount of vegetation and urban geometry (Alexandri et al., 2006).

1.1.1 Background

The benefits of green walls and roofs have been studied since the seventies (Bellomo, 2003). Green façades and roofs offer improvements in the efficiency of the building, as well as having environmental and ecological benefits. Both systems can help reduce the urban heat island effect and improve air quality; providing shade, and insulation through the evapotranspiration of the plants (Perini et al., 2011).

The urban heat island effect was recognized in the nineteenth century by climatologists, who measured differences in city temperatures and the countryside (Kleerekoper et al., 2011). Current urban development practices often start with the removal of trees and other vegetation (Kleerekoper et al., 2011). This process of removing trees and vegetation reduces the cooling effects provided by vegetation and moist soils. This effect is increased in areas with tall buildings and narrow streets, because the heat can be trapped, and the airflow is reduced. In addition, waste heat from air conditioning, vehicles, and industrial processes adds further to the city's heat load (EPA, 2009). The urban heat island effects can increase the temperature six to eight degrees Fahrenheit (EPA, 2009) and generate a microclimate in the downtown area. For example, the city of Dallas has an average high winter temperature of sixty-one degrees Fahrenheit and, an average high summer temperature of ninety-six degrees

Fahrenheit according to the National Weather Service. The rapid growth of North-Central Texas, specifically the sub-urban sprawl interlinking the major cities, has triggered land use changes, causing more impervious surfaces, such as buildings, highways, roads parking lots and others, increasing air pollution and energy consumption (Winguth and Kelp, 2013). The implementation of vegetation and soil to the surface of roofs and walls can lessen the negative effects of buildings, reduce the urban heat island effects, and reduce the energy consumption of the building itself (Oberndorfer et al., 2007). In the past, green walls have been used mainly for ornamental or horticultural purposes (Dunnet and Kingsbury, 2008; Kohler, 2008; Francis and Lorimer, 2011).

1.2 Problem Statement

The implementation of green walls and roofs has increased over the past few years, but the impact of these types of landscape features to larger urban green infrastructure has not been studied in the city of Dallas, Texas. Numerous articles have been written about the environmental and ecological benefits of green walls and roofs in others parts of the World (Francis and Lorimer, 2011; Thani et al., 2012; Oberndorfer et al., 2007; Perez et al., 2011; Ottele et al., 2011; Alexandri and Jones, 2006; Mazzali et al., 2013; Santamouris, 2012) but some of this literature was either too specific to constructed experiments or other defined geographies, or opinion pieces that provide little empirical evidence. Furthermore, there is no specific literature that looks at green walls and roofs and their impact to urban heath island effects in North Central Texas. The literature is instrumental in understanding the general benefits of green walls and roofs but their likely impact on environmental issues specifically the urban heat island effect in urban areas is prone to more research.

The purpose of this research is to study the impact of green walls and roofs on the urban heat island effects in the central business district of Dallas, Texas. This research explores microclimate and uses a scaled model of downtown Dallas as a simulated environment for testing and illustration of the potential impacts of green walls and roofs on the heat island effects of this area of study. This research first reviews the relevant scholarly research concerning green walls and roofs and identifies key attributes concerning impacts, as well as their strengths and weaknesses. Then, it produces physical simulations to observe, test and demonstrate their likely impact on the urban environment, specifically the urban heath island effects. The research focuses on wind and solar exposure simulations at various scales, from a single building to a district, to understand and visualize such impacts. Simulations suggest that incorporating green roofs and walls to an urban environment on existing or new buildings in a district can help alleviate the inclemency of the environment.

1.3 Research Questions

The questions explored in the research include:

1. Can green walls and roofs influence the solar exposure of buildings and districts to alleviate urban heat island effect in downtown Dallas?
2. Can green walls and roofs influence the seasonal wind patterns to alleviate urban heat island effect in downtown Dallas?
3. Can green walls and roofs help reduce the urban heat island effect in a dense urban area such as downtown Dallas?

1.4 Research Methods

This research seeks empirical evidence to study the questions outlined above. The collection of data about green walls and green roofs, urban heat island effect in Dallas, Texas, and an on-site survey of the actual green walls and roofs of the Main Street District set the parameters of the simulation. Two models were made to simulate a portion of the Main Street District in Dallas, Texas; sun and seasonal wind studies were made on the models before adding green walls and roofs, and after adding green walls and roofs. These comparative simulations are visually analyzed to inform the likely impact of green roofs and walls to sun exposure and seasonal wind patterns, and the effect on the reduction of the urban heat island effects.

1.5 Definition of Terms

Albedo: The percentage of incident radiation reflected by material. Usage of the term in earth science is usually limited to shortwave radiation and landscape materials (Marsh, 2010).

Anthropogenic heat: Heat produced by human activities (Wong et al., 2008).

Central Business District (CBD): The commercial and often geographic heart of a city; the downtown section of a city, generally consisting of retail, office, hotel, entertainment, and high density housing (EPA, 2009).

Climate: The representative or general conditions of the atmosphere at a place on earth. It is more than the average conditions of the atmosphere, for climate may also include extreme and infrequent conditions (Marsh, 2010).

Ecological design: Design that minimizes destructive environmental impacts by integrating with living processes to the possible extent (Hopper, 2007).

Ecosystem: A group of organisms linked together by a flow of energy; also a community of organisms and their environment (Marsh, 2010).

Environment: The combination of external physical conditions that affect and influence the growth, development, and survival of organisms (Alberti et al., 2003).

Environmental impact: The consequence a certain action will produce on the elements of the environment or on the environmental units (Martinez-Falero and Gonzalez-Alonso, 1995).

Evapotranspiration: The loss of water from the soil through evaporation and transpiration (Marsh, 2010).

Façade: A barrier that acts against environmental conditions, to separate the building interior and exterior (Ottele et al., 2011).

Green façade: A wall that involves the establishment of climbing plants that are encouraged to grow up and attach to the walls of the buildings to form a green covering (Francis and Lorimer, 2011).

Green infrastructure: Interconnected network of open spaces and natural areas (such as greenways, wetlands, parks, and forest preserves) that naturally recharges aquifers, improves water quality, and provides recreational opportunities and wildlife habitats (Benedict and McMahon, 2006).

Green roof: Is a roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane; it may also include additional layers such as a root barrier and drainage and irrigation systems (Oberndorfer et al., 2007).

Green wall: Living walls or green walls are self-sufficient vertical gardens that are attached to the exterior or interior of a building; they differ from green façades (e.g. ivy walls) in that the plants root in a structural support is fastened to the wall itself (Perez et al., 2011).

Habitat: The local environment of an organism from which it gains its resources; habitat is often variable in size, content, and location, changing with the phases in an organism's life cycle (Marsh, 2010)

Heat flux density: Is the short and long wave radiation of heat (Alexandri and Jones, 2006).

Heliodon: Is a machine that simulates the interactions of the sun with the building environment, and elements of the landscape (McDermott et al., 2013).

Hydroponic: Using balanced nutrient solutions to provide the required nutrients to plant's food and water requirements (Ottele et al., 2011).

Impervious cover: Any hard surface material, such as asphalt or concrete, that limits infiltration and induces high runoff rates (Marsh, 2010).

Leadership in Energy and Environmental Design (LEED): LEED is a green building tool that addresses the entire building lifecycle recognizing best-in-class building strategies (USGBC, 2012).

Low Impact Development (LID): Land use development designed specifically to minimize environmental impact in terms of energy use, air pollution, storm water runoff, and land consumption; applies to architecture, landscape architecture, and landscape planning (Marsh, 2010).

Living Architecture: Living systems within the built environment, such as green roofs, green walls and vegetated swales, that can act as a bridge to alleviate the increased demands placed on existing infrastructure. This concept, also known as Living Architecture, promotes biomass to cool urban areas, support the growth of tree canopies to improve air quality and rain gardens to mitigate stormwater runoff (Greenscreen, 2012).

Living Wall: A wall that incorporates vegetation to its structure or on its surface but that does not require the plants to be rooted at the base of the wall (Francis and Lorimer, 2011).

Microclimate: The climate of small spaces such as an inner city, residential area, or mountain valley (Marsh, 2010).

Mitigation: A measured used to lessen the impact of an action on the natural or human environment (Marsh, 2010).

Planar Laser Induced Fluorescence (PLIF): Use to investigate simulated flow patterns in a building or urban area in three dimensions (McDermott et al., 2013).

Phototropism Effect: The way plants move in order to get sunlight (Ottele et al., 2011).

Stagnant Air Layer: The space between the façade and the dense vertical green layer for both systems: rooted on the soil or rooted in artificial pre-vegetated based systems (Ottele et al., 2011).

Sustainability: The property of a material or product that specifies whether and to what extent the principal requirements are met in a specific application. The requirements relate to water, air and soil loading, and their influence on wellbeing and health of living creatures, the use of raw materials and energy, and also consequences for the landscape, the creation of waste and manifestation of nuisance surrounding environment (Ottele et al., 2011).

Urban Climate: The climate in and around urban areas; it is usually somewhat warmer, foggier, and less well lighted than the climate of the surrounding region (Marsh, 2010).

Urban Ecosystems: The cities, towns, and urban strips constructed by humans (Alberti et al., 2003).

Urban Heat Island Effects: The area or patch of relatively warm air that develops over urbanized areas (Kleerekoper et al., 2011)

Shallow Water Table: Used to investigate simulated flow patterns of a building footprint or site plan, or cross sections in two dimensions (McDermott et al., 2013).

Wind Rose: A map that compiles information about the wind at a particular location and over a specific time period. Used by meteorologists' to study the percentage of the time the wind blows from each direction during a certain period (NRCS, 2013).

1.6 Limitations and Significance

This study focuses on the impact that green walls and roofs have mainly in a simulated environment and how they can help reduce the urban heat island effect of dense urban areas, specifically downtown Dallas. A simulation of a defined area of the Main Street District was modeled in order to study the wind and sun patterns and test the impact of green walls and roofs with the specific climatic conditions. The city of Dallas does not have a list or any kind of data regarding the existing green walls and roofs.

The use of green walls and roofs is not a new topic, but the relationship between those kinds of green infrastructure and the impact that they have in the built environment, is relatively new. In the past, green walls have been used mainly for ornamental or horticultural purposes (Dunnet and Kingsbury, 2008; Kohler, 2008; Francis and Lorimer, 2011). Since the application of these systems does not have a long history, there is still much to learn about their functions, benefits and limitations. The implementation of green walls and roofs within LEED requirements is helping in the knowledge and investigation. This research is designed to be a reference for future use for landscape design techniques in reducing the urban heat island effect. There is still much to learn about the effect of green walls and roofs in the urban microclimate. By doing simulated experiments, the empirical data obtained becomes more tangible.

When conducting a simulated experiment, there are some limitations. The size and scale of the models were determined by the apparatus of each experiment. Materials for the models were also determined by the apparatus and by the period of time available to conduct this research. If more time was available, this investigation could have taken further evaluation, and additional simulation experiments could have been done in order to have a better understanding of the impact of green walls and roofs in the urban microclimate. The limitations of this research are beyond the researcher's control.

1.7 Assumptions

It is assumed that the examples found from other cities in the world and the beneficial impact that living architecture, such as green walls and roofs have had in them, is a similar beneficial impact that it can have in downtown Dallas if more green façades and roofs were to be placed. The specific benefits vary from region to region, according to the characteristics and climatological conditions of the area, this study is specific to Dallas, Texas. It is also assumed that the simulation is truthful enough to obtain significant information. The placement of the green walls and roofs for the simulation is not a proposal but an investigation on their impact.

1.8 Summary

The urban heat island effect is the main type of microclimate seen in urban areas (Kleerekoper et al., 2012). North-Central Texas is growing fast and is expected to nearly double its population adding more impervious surface by the year 2050 (Vision North Texas). Existing conditions as well as projected growth is likely to elevate urban heat island effects not only in the cities but also the downtown areas (Winguth and Kelp, 2013). The use of green walls and green roofs can help alleviate the impact of existing or new buildings. They promote biomass to cool urban areas, support the growth of tree canopies, improve air quality, and mitigate stormwater runoff (Greenscreen, 2012).

This chapter explained the background of the research as well as the research objective. The definition of the terms helps the reader understand the major concepts of this research and the context in which they are used. The following chapter focuses on the existing literature and the value and impact of green walls and roofs in an urban environment. Subsequent chapters present the methodology adopted in this research as well as the findings of the research and conclusions.

Chapter 2

Literature Review

2.1 Introduction

This chapter presents a review of research and literature on the various types of green walls and roofs and their history, as wells as the environmental impact that green walls and roofs have in buildings, and the opportunities they bring to reduce the urban heat island effect and microclimate in downtown Dallas. This chapter also covers why simulations are important and relevant in design literature. In addition, an overview of other research done in different cities was reviewed in order to understand the impact and the process of informing where to place new green walls and roofs. The review provides the basis for understanding where and why is important to add green walls and roofs in downtown Dallas.

2.2 Green Walls and Green Roofs

2.2.1 Green Walls

Green walls, or green façades, have been used historically as an ornamental or horticultural element. History tells us the first documented green structures were the hanging gardens of Babylon (Francis and Lorimer, 2011). Green walls are the result of greening vertical surfaces with plants, whether plants that are rooted into the ground, in the wall itself, or in modular panels that are attached to the façade. Green walls are vegetated vertical surfaces that are classified into two categories (see Table 2.1 for additional definitions):

1) Green façades are façades systems in which climbing plants are rooted in the soil or containers, either growing upwards or cascading down, and they require a structure in order to maintain their position, growth and overall survival. With green façades, a broad variety of plant species can be used and this system is easily scalable

(Greenscreen, 2012). Green façades can subsequently be divided into three systems: *traditional green façades,* where climbing plants use the façade material as support (see figure 2.1), and, by doing this, the climbers are planted in the ground at the base of the building, this being the cheapest of all the green façade systems. Using these system could damage the façade, and the plants being planted like this can grow up to eighty-two feet height and can take several years (Ottele et al., 2011). *Double skin green façade,* or green curtain, is when the façade is separated from the wall (see figure 2.2). And lastly, *perimeter flowerpots*, when part of the composition of the façade hanging pot shrubs are planted around the building, creating a green curtain (Perez et al., 2011) (see figure 2.3).

Figure 2.1 Example of Traditional Green Façade, Miami, Florida (Ozdil, 2013)

Figure 2.2 Double Skin Green Facade (Perez, 2010)

Figure 2.3 Perimeter Flowerpots

2) Living walls are a new technology system that depend on prefabricated modular or monolithic vertical soil or hydroponic system to root plants on a vertical plane (Greenscreen, 2012). They are made of panels and/or geotextiles felts. Sometimes they

are pre-cultivated and fixed to a vertical support on the wall. The geotextile felt work by providing support to the different plant materials (Perez et al., 2011). A living wall can be thought of as a vertical garden, which means it requires the maintenance and care that a regular garden would need, such as irrigation, drainage, and how to organize everything vertically (see figure 2.4). Since it is a new technology, it has been hard to make the plants survive for a long period of time and over a large surface. It is also more expensive to produce a living wall system verses a green façade during the installation, maintenance and replacement of the plants (Greenscreen, 2012).

Figure 2.4 Living Wall in Mexico City (KaneSterling, 2013)

Green vertical systems can also be classified into two construction systems: extensive and intensive. Extensive systems are easy to build and require minimum future maintenance after construction; intensive systems are more complicated and require a high level of maintenance after construction.

Table 2.1 Green Walls Definition of Typologies

Terminology	**Definition**
Green façade	Refers to climbing plants that are encouraged to grow up and along the walls of buildings to form a green covering, the roots of the plants are contained at the base of the wall. Sometimes these plants are intended to grow on a wire or trellis framework (Francis and Lorimer, 2011; Greenscreen, 2012).
Living wall	A wall that incorporates vegetation on its structure or surface that does not require the plants to be rooted at the base of the wall as in a green façade. Most living walls are modular systems and consist on an encased growing medium that is placed onto the wall surface but separated from the wall material through a waterproof membrane and watered using a drip-feed system. Sometimes they can be bioengineered so that the plants roots are used as reinforcing mechanism within the wall system (Francis and Lorimer, 2011; Greenscreen, 2012).
Biowall	A living wall or green façade that is placed indoors. It is used to enhance the atmosphere and indoor environment (Francis and Lorimer, 2011; Greenscreen, 2012.

Green vertical systems can be used as passive energy saving systems through four mechanisms: the interception of solar radiation as a consequence of the shadow produced by the vegetation, the insulation that the vegetation produces when attached to a building wall, blocking the wind, and the evaporative cooling effect that occurs by evapotranspiration of the plants (Perez et al., 2011).

Starting with solar radiation as a consequence of the shadow produced by the vegetation, it has been observed that an area covered with shade trees can save up to thirty percent of cooling energy. "In experimenting with traditional green façades Köhler (2007 & 2008) found that the magnitude of this shadow effect depends on the density of the foliage. Ivies are the species that provide the maximum cooling effect, comparable to the shade of trees. Differences up to three degrees Celsius in indoor temperature in winter were found" (Köhler, 2007, 2008 in Perez et al., 2011, p. 4856). This process works by filtering the direct sunlight on a façade with leaves. Through the phototropism effect, where one-hundred percent of the light falls into the leaves, five to thirty percent of that light is reflected, five to twenty percent of that light is used for photosynthesis, ten to fifty percent is transformed into heat, twenty to forty percent is used for evapotranspiration and five to thirty percent is passed through the leaves (Ottele et al., 2011). Recent studies have shown that climbing plants also provide a cooling effect on the building's surface, even in the hot periods of the year, which is very valuable in warm climates (Perez et al., 2011; Ottele et al., 2011).

Secondly, the insulation that the vegetation produces between the green screen and the building walls generates changes in the ambient conditions such as temperature and humidity. The space between the building and the green façade creates a stagnant air layer developing an insulation effect (Ottele et al., 2011). The insulation capacity of living walls can depend on the substrate thickness. When a concrete wall is covered with vegetation, the heat transfer is lower than with a concrete wall that is not covered; a living wall can reduce the energy that is transferred to the building by 0.24 kW h/m2 (Hoyano, 1988). "In studies on traditional façades an improvement in heat loss up to twenty five percent in a northern façade was measured, although this improvement depended on the insulation levels of the building" (Köhler, 2008 in Perez et al., 2011, p. 4856).

Thirdly, a green wall system acts as a wind barrier and, as a consequence, blocks the effects of winds on the façades of a building. The effect depends on a series of specifications: the density and permeability of the vegetation, the orientation of the wall, and the direction and velocity of the wind itself. All these measurements help increase the energy efficiency of a building by blocking the wind alone, reducing the demand of air conditioning in the summer, and heat in the winter (Dinsdale et al. in Perez et al., 2011). When using green façades as a component to block the wind, it is important not to obstruct the ventilation in the summer and not to help in the circulation of cold air in the winter. Wind decreases the energy efficiency of a building by fifty percent according to Ottele et al. (2011), but, by applying a plant layer, the green façade acts as a buffer and prevents the wind from moving alongside the building surface.

The last of the passive energy saving mechanisms through green walls is the evaporative cooling effect through evapotranspiration, which requires energy. This evaporative cooling effect depends on the type of plants and their exposure. It has been studied that when an area is covered with trees the cooling effect due to evapotranspiration of plants resulted in a temperature decrease around the buildings. Green façades cool the air through evapotranspiration, and as a result, for every decrease in internal air temperature of a building of five degrees Celsius, the use of electricity in the building for the air-conditioning system could be reduced by eight percent in the summer. In the winter the heat radiation of the exterior walls is insulated by the vegetation (Ottele et al., 2011). "According to Wong (2009, 2010) since insulation applied to the exterior of buildings is much more effective than interior insulation, especially during the summer months, vertical greenery systems would have the two fold effect of reducing incoming solar energy into the interior through shading and reducing heat flow into the building through evaporative cooling, both increasing energy savings" (Perez et al., 2011, p. 4857).

2.2.2 Green Roofs

Planting vegetation on the roofs of buildings has been taking place since the hanging gardens of Babylon. They were used as a horticultural and architectural elements, but recently this practice has been gain more momentum to protect the building tops from the impact of solar radiation, precipitation and wind. Green roofs are believed to improve energy efficiency, mediate storm water impact, attract fauna in urban regions (Brenneissen, 2006; Orberndorfer et al., 2007 in Francis and Lorimer, 2011) and provide access to nature and recreation in one of the least expected parts of buildings. A green roof can be a flat or sloped roof surface designed to support vegetation besides working as a fully functioning roof (Goddard et al., 2009). Green roofs have several layers: waterproofing, root-barrier, drainage and filter membranes; the substrate layer is sited to allow vegetation to grow (Dvorak and Volder, 2010). "Green roofs support plant communities that are tolerant to the extreme weather conditions encountered on rooftops. The thicker the substrate layer is, the more diversified the vegetation can be" (Henry and Frascaria-Lacoste, 2012, p. 91). Two different types of green roofs exist: *extensive* which has a thin substrate layer, and *intensive* which has a thicker substrate layer (see table 2.2 for definitions). The extensive system is more common because the cost is lower and the implementation is easier (Henry and Frascaria-Lacoste, 2012; EPA, 2009).

Intensive living roofs are accessible installations with a thicker substrate layer that allows a variety in plant choices from ground covers to trees. Usually these types of systems permit the space to function as a usable area and it is mainly used in commercial buildings. The intensive systems may require significant maintenance and their cost are typically higher too (House, 2009) (see figure 2.5).

Figure 2.5 Intensive Green Roof (Winter Street Architects, 2010)

Extensive living roofs are usually inaccessible installations with a thinner substrate layer. Because of the thin membrane, the variety of plants and sizes are limited. An extensive living roof is more common because of the low maintenance cost and because it can be added to an existing building without much preparation. There are two types of extensive green roofs: monolithic and modular. Monolithic systems cover the roof area (see figure 2.6) while modular systems use containers (see figure 2.7) (EPA, 2009).

Figure 2.6 Extensive Living Roof Monolithic System (SIG Design and Technology, 2013)

Figure 2.7 Extensive Living Roof Modular System (Greenroofs, 2013)

Table 2.2 Green Roofs Definition of Typologies

Terminology	Definition
Green roof	Planted living roof (Oberndorfer, 2007; Francis and Lorimer, 2011).
Living roof	Any vegetated roof system either 'brown' or 'green' (Oberndorfer, 2007; Francis and Lorimer, 2011).
Intensive living/green roof	A 'roof garden' where the purpose is mainly recreational or aesthetic like a regular garden. This type of roofs will have deeper soil, require regular maintenance and can support a wide variety of plants (Oberndorfer, 2007; Francis and Lorimer, 2011).
Extensive living/green roof	A roof generated to support biodiversity or other environmental benefits, and is not intended to be used by humans. Usually it contains a thinner soil layer and after construction it requires minimal maintenance (Oberndorfer, 2007; Francis and Lorimer, 2011).

When a building is built, there is a change in the flow of energy and substance through urban ecosystems, often causing environmental problems (Oberndorfer et al. 2007). By altering the superficial properties of the buildings, you can mitigate the environmental problems they can cause. Roofs can represent up to thirty-two percent of the horizontal surface in built-up areas (Frazer, 2005), and are important determinants of energy flux and of buildings’ water relations. When vegetation and soil are added to roof surfaces, the negative impact on buildings can be lessened, reducing the buildings' energy consumption. Living, or green roofs, have been shown to increase sound insulation (Dunnett and Kingsbury, 2004), fire resistance (Köhler, 2003), and the longevity of the roof membrane (Porsche and Köhler, 2003). They can reduce the energy required for the maintenance of interior climates (Del Barrio, 1998), because vegetation and growing plant media intercept and dissipate solar radiation. "Green roofs can also mitigate storm-water run-off from building surfaces by collecting and retaining precipitation, thereby reducing the volume of flow into storm-water infrastructure and urban waterways" (Oberndorfer et al., 2007, p. 824). Other benefits of green roofs are that they can become a green-space amenity, habitat for wildlife, air-quality improvement, and reduce the urban heat island effect (Getter and Rowe, 2006). Even though green roofs are initially more expensive to construct than conventional roofs, the long term advantages are worth it because of the energy saved and the longevity of roof membranes (Porsche and Köhler, 2003). "The environmental benefits provided by green roofs derive from their functioning as ecosystems" (Oberndorfer et al., 2007, p. 824).

It is important to consider that the climatic conditions on the roof-top of buildings can be extreme because of the rainfall, temperature and high winds. Because of the conditions previously mentioned, the plant palette can be limited. The use of native plants "are generally considered ideal choices for [rooftop] landscapes because of their adaptations to local climates, and the native stress-tolerant floras (particularly dry grassland, coastal, and alpine floras) of many regions offer opportunities for trial and experiment" (Oberndorfer et al., 2007, p.827). The benefits of green roofs fall into three main categories: storm-water management; energy conservation; and urban habitat provision. Urban areas have more impervious surfaces than pervious, which causes storm-water to be hard to manage; because of this, green roofs can become a good storm-water management infrastructure. “In addition to exacerbating flooding, erosion, and sedimentation, urban runoff is also high in pollutants such as pesticides and petroleum residues, which harm wildlife habitats and contaminate drinking supplies” (Moran et al., 2005, p.6). Other types of storm-water infrastructures are constructed wetlands, ponds, sand filters, and rain gardens; unfortunately, they can be hard to implement in dense urban areas. Green roofs work as an urban storm-water management infrastructure, because they make use of existing roof space and prevent runoff before it leaves the lot (Oberndorfer et al., 2007). A green roof has the greatest effect on energy consumption for buildings that have high roof to wall area ratios (Oberndorfer et al., 2007).

2.2.3 Recent Research on Green Walls and Green Roofs

The employment of green walls and roofs is not a new concept as it is widely covered in the recent literature. Green walls and green roofs present economic, social and environmental benefits. Greening façades and green roofs represent a combination of nature and buildings that can help address environmental issues, especially in dense urban areas. They help increase biodiversity and ecological value, mitigate the urban heat island effect, reduce the temperature of a building inside and out, provide insulation, improve air quality, and the social and psychological wellbeing of the citizens (Ottele, 2011). The following table illustrates some of the most recent published research on the topic with their emphasis areas.

Table 2.3 Green Walls and Green Roofs Literature Review Matrix

Author (s)	Article Title	Date of Publication	Category or Emphasis
Francis and Lorimer	Urban Reconciliation ecology: The potential of living roofs and walls	2011	Biodiversity potential of living roofs and walls

Table 2.3 - Continued

Oberndorfer et al.	Green Roofs as Urban Ecosystems: Ecological Structures, Functions and Services	2007	Potential of green roofs to act as ecosystems
Perez et al.	Green vertical systems for buildings as a passive systems for energy savings	2011	Green walls acting as wind barriers, generates microclimate between building façade and green wall
Ottele et al.	Comparative life cycle analysis for green façades and living wall systems	2011	Ecological and environmental benefits of green walls
Alexandri and Jones	Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates	2006	Green walls and roofs help lower temperature in the urban canyon
Perini et al.	Vertical greening systems and the effect on air flow and temperature on the building envelope	2011	The impact of green walls and roofs in the thermal performance of the building and the effect in the urban environment
Green Screen	Considerations for Advanced Green Façade Design	2012	Living Architecture
Mazzali et al.	Experimental investigation on the energy performance of Living Walls in a temperate climate	2013	Living walls serve as a cooling energy reduction
Santamouris	Cooling the cities. A review of reflective and green roof mitigation technologies to reduce heat island and improve comfort in urban environments	2012	Mitigation potential of green roofs
Blanc	The Vertical Garden A scientific and Artistic approach	2008	Green walls as a second skin of buildings
Susorova et al.	A model of vegetated exterior façades for evaluation of wall thermal performance	2013	Reduction of temperature inside and outside of building when green façade is placed

2.3 Urban Heat Island Effects

2.3.1 Microclimate

Since the beginning of the human existence, man has tried to alter the microclimate in order to build a more human friendly environment, to protect and shelter mankind from extreme weather conditions. Especially after the Industrial Revolution, urban spaces started growing more dramatically. Cities became bigger, using more man-made materials, impacting the natural conditions and vegetation creating an alteration in the climatic characteristics of urban spaces. All these changes have affected the climatic conditions of urban areas, specifically the center of cities where the high density of buildings and reflective materials can be seen, causing a rise in the temperature known as the urban heat island effect (Alexandri and Jones, 2006).

2.3.2 Definition of Urban Heat Island Effects

When a building is built, there is a change in the flow of energy and substance through urban ecosystems, often causing environmental problems (Oberndorfer et al. 2007). Urban areas are usually warmer than rural areas because of a higher ratio of buildings and infrastructure concentrated in the space, causing the temperature to increase (Winguth and Kelp, 2013). The “sensible heat storage of urban surfaces, reduced wind speed and albedo in response to increased surfaced roughness, advective heat contribution from upstream urban areas, and other related factors, like anthropogenic heat flux linked to population density with associated building and traffic heat loss. The climate of the urban boundary layer is determined, at least partially, by the exchanges of momentum, heat and water with the urban canopy layer.” (Landsberg, 1981, Christen and Vogt, 2004, Voogt, 2010; Oke, 1987, Zhang et al., 2011 in Winguth and Kelp, 2013, p. 4). The urban heat island effect causes serious climatic unpleasant conditions in the human health, animals, and vegetation (Kleerekoper et al., 2011). This effect is seen especially in cities where the summer season is extreme and hot. The moderation of extreme heat in these cities is important for their sustainability and to lower the risks and effects of such conditions. The urban heat island effects has an urban canopy layer that is categorized by small processes that are affected by characteristics of development, such as the urban canyon geometry and the reduction of the sky view factor (see figure 2.8). The canopy layer reaches its maximum after sunset, particularly when the skies are clear and the wind is low in speed (Winguth and Kelp, 2013).

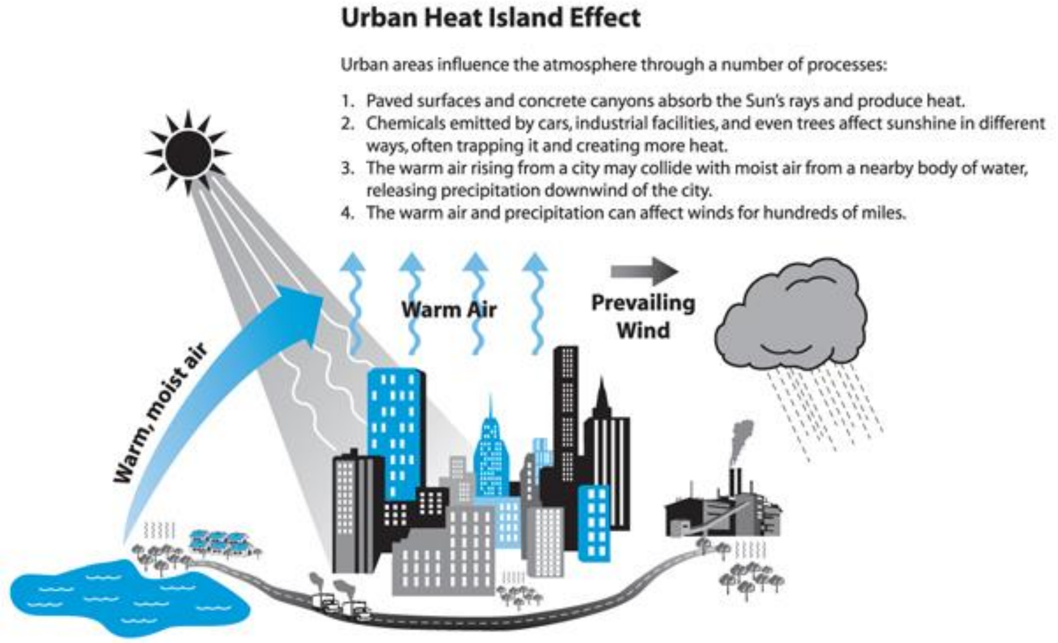

Figure 2.8 Urban Heat Island Effect Diagram (UCAR, 2006)

In the urban environment the temperature increases because of the dark and impervious surfaces such as asphalt roads and roofs. Usually the downtown area of a city that has high-rise buildings and high-density becomes warmer than the surrounding areas. The urban heat island effect can be reduced by increasing albedo, or by applying more vegetation cover with sufficient soil moisture for evapotranspiration (Bass et al., 2002). According to Kleerekoper et al., the urban heat island effect can be caused by the following (see figure 2.9):

1. The absorption of short-wave radiation from the sun in low albedo materials, this heat has been trapped by multiple reflections between buildings and street surfaces.

2. The air pollution in the urban atmosphere gets absorbed, and re-emits long-wave radiation to the urban environment.

3. The obstruction of the sky by buildings resulting in a decreased long-wave radiative heat loss from street canyons. Causing the heat to get intercepted by the obstructing surfaces, and absorbed or radiated back into the urban tissue.

4. The release of anthropogenic heat by combustion processes, such as traffic, space heating and industries.

5. The increased heat storage by building materials with large thermal access. Additionally, cities have a larger surface area compared to rural areas causing more heat to be stored.

6. The evaporation from urban areas is decreased because of ‘waterproofed surfaces’ – causing less permeable materials, and less vegetation compared to rural areas.

7. The turbulent heat transport from within streets is diminished by a reduction of wind speed (Kleerekoper et al., 2011, p. 30).

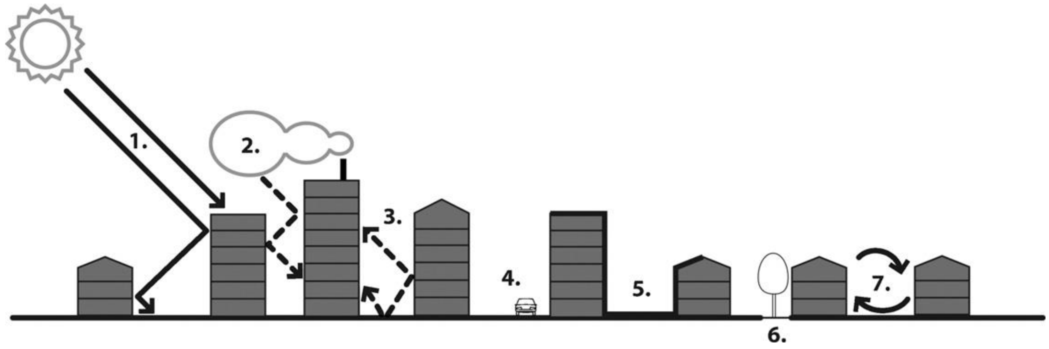

Figure 2.9 Causes of Urban Heat Islands (Kleerekoper et al., 2011)

2.3.2.1 Urban Form

Urban form affects the climate of cities. Especially within the central business district where the concentration of buildings is more intense than the rest of the city climate is altered. Urban forms changes over time according to human needs (Carmona et al., 2003). "The influence of urban form and function on the background climate for the most part remain in the realm of urban climatology, however there have been some studies outside this discipline that have examined the role of form and function as an energy management parameter. Strømann-Andersen and Sattrup found that the energy performance of low-energy buildings in a north-European setting is affected by the geometry of urban canyons within the range of up to thirty percent (offices) and nineteen percent (residential), demonstrating the urban form as a key factor in energy use in buildings" (Strømann-Andersen and Sattrup, 2011 in Futcher et al. 2013, p. 113).

2.3.3 Vegetation as a Strategy to Mitigate the Urban Heat Island Effect

Studies show that a lack of vegetation is the primary condition to such effect, "by placing vegetation within the built space of the urban fabric, raised urban temperatures can decrease within the human habitats themselves and not only in the detached spaces of parks" (Alexandri and Jones, 2006, p.480). Urban surfaces such as the building envelope (walls and roofs) when covered with vegetation can alter the microclimate of the built environment, as well as the local climate of the city. There are some tools and strategies for urban design that can help alleviate the accumulation of heat by applying cooling techniques and thereby reducing the urban heat island effect:

Vegetation

Vegetation cools the environment through evapotranspiration and also by creating a shading surface that otherwise absorbs short-wave radiation. There are four types of applications of green infrastructure in urban environments: parks, street trees, private gardens, and green walls or roofs (Kleerekoper et al., 2012). "Vegetation has an average cooling effect of one to four point seven degree Celsius that spread one hundred to one thousand meters into an urban area, but this is highly dependent upon the amount of water the plant or tree has available" (Kleerekoper et al., 2012, p. 32). "Green infrastructure can be considered a conceptual framework for understanding the valuable services nature provides the human environment." At the national or regional level, interconnected networks of park systems and wildlife corridors preserve ecological function, manage water, provide wildlife habitat, and create a balance between built and natural environments. At the urban level, parks and urban forestry are central to reducing energy usage costs and creating clean, temperate air. Lastly, green roofs, walls, and other techniques within or on buildings bring a range of benefits, including reduced energy consumption and dramatically decreased stormwater runoff. At all scales, green infrastructure provides real ecological, economic, and social benefits" (ASLA, 2013).

Particularly green walls and roofs have the most significant cooling effects on the urban environment and also on the individual buildings where they are placed. This effect is possible through: evapotranspiration of the leaves, converting heat into latent heat through evaporation from the soil and by preventing the absorption of short-wave radiation by low albedo materials through shading (Kleerekoper et al., 2012). The temperature inside the buildings also gets affected because of the high insulation the green façade or roofs generates. This helps the building maintain the heat outside in the summer and inside in the winter. Through green walls and roofs, the urban heat island effect can be reduced by providing green infrastructure that could improve the environmental conditions. "A lack of greening possibilities in streets should be compensated with surface water, green façades and permeable pavements" (Kleerekoper et al., 2011, p. 34).

2.3.4 Dallas Urban Heat Island Effect

The area of North-Central Texas (also known as North Texas) is defined by sixteen counties that are confined in a surface of thirty-three thousand, one hundred thirty-eight square kilometers. It is the fourth largest metropolitan area of the United States and includes the city of Dallas and Fort Worth. The coordinates of the city of Dallas are 32° 46' °N, 96° 48' °W; the elevations vary from one hundred and twenty to three-hundred and fifty meters, and it lies in the upper margin of the coastal plain (Winguth and Kelp, 2013, p.4). "Between 2000 and 2010, it experienced a population density growth of approximately twenty-three percent. By 2050 is projected to be a "megacity" with approximately fifteen million inhabitants" (Vision North Texas, 2009, in Winguth and Kelp, 2013, p.4). The rapid growth of North-Central Texas, specifically the sub-urban sprawl interlinking the major cities, has triggered land use changes, causing more impervious surfaces, such as buildings, highways, roads parking lots and others, increasing air pollution and energy consumption (Winguth and Kelp, 2013).

Dallas' climate is categorized as humid subtropical, with eight months of the year having a temperature above sixty eight degrees Fahrenheit with dry winters. The city receives most of its precipitation in the spring with some heavy-rains occurring in the summer for brief periods of time (Winguth and Kelp, 2013). The urban heat island effect occurs before sunrise, at that time, the difference between urban and rural temperatures is often at its highest (see figure 2.10, 2.11). There are two basic types of heat island effect, at the surface, and atmospheric. The surface temperature differences occur mainly in the daytime and can range from eighteen to twenty-seven degrees Fahrenheit. Atmospheric differences are mainly at night and can range from thirteen to twenty-two degrees Fahrenheit. A study of Dallas and Houston found that urban summer nighttime temperatures were almost four degrees Fahrenheit warmer than rural temperatures, this average was done over 2000 to 2006. The greatest differences observed, occurred around six a.m., and during the day, urban temperatures averaged almost two degrees Fahrenheit above the rural ones. The same study showed that the Dallas daytime heat island effect was more evident than Houston's (HARC and EPA, 2009).

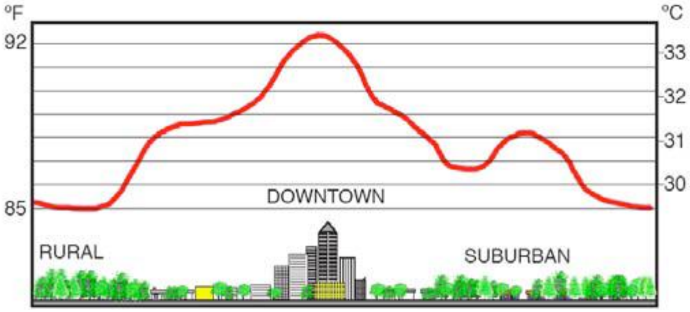

Figure 2.10 Urban heat island effect (HARC and EPA, 2009)

Dallas is facing critical challenges because of the high seasonal temperatures including rising energy costs, air quality, and health. Because of the higher temperatures, the demand for electricity for air conditioning rises, especially in the summer time. The literature suggested that the cost of additional electricity caused by the urban heat island effects in Dallas may reach to several hundred million dollars per year, when compared to other cities (HARC and EPA, 2009). "Widespread heat island mitigation measures, such as cool roofs and extensive tree planting, could produce energy savings of forty to fifty million dollars annually. These savings would be offset somewhat by the costs of implementing these measures, but the net benefit would be substantial" (HARC and EPA, 2009, p. 5).

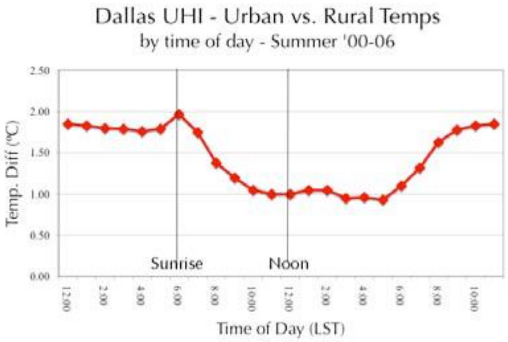

Figure 2.11 Dallas urban heat island effects: rural vs. urban (HARC and EPA, 2009)

As the temperature increases, the level of ozone also increases, which becomes the key pollutant of concern for the Dallas - Fort Worth area. Also, as the temperature increases, evaporative emissions of volatile organic compounds, such as gasoline, while forcing biogenic emissions from trees to higher levels, rises as well. "Estimates from the heat island Mitigation Impact Screening Tool (MIST) suggest that a one degree Fahrenheit temperature reduction could reduce ozone by as much as one point two parts per billion (ppb), equal to one point six percent of the new federal eight-hour ozone standard of seventy-five ppb" (HARC and EPA, 2009, p.5).

Higher temperatures, particularly during heat waves, also affect the human health. There are many heat related illnesses that occur during such events, even in Texas where there is more adaptation by people and buildings to higher temperatures than in cooler climates. Dallas has experienced extended heat waves in nineteen-eighty, nineteen-ninety-six, and nineteen-ninety-eight, having several weeks of one hundred degrees Fahrenheit and higher temperatures (HARC and EPA, 2009).

Figure 2.12 Dallas tree canopy (HARC and EPA, 2009)

During the daytime, the cooler surface areas are the ones covered with vegetation or water, specifically with urban tree canopy and wetter areas along waterways, such as the Trinity River and all of its tributaries. In general, the more tree cover, the cooler the daytime surface temperatures (see figure 2.12). "Areas with older, larger trees do not reflect a great deal of solar radiation, but shade surfaces that would otherwise absorb and store this energy" (HARC and EPA, 2009, p.6). It has been found that the air temperature in heavily vegetated urban areas may stay slightly warmer during nighttime in the summer due to reduced airflow.

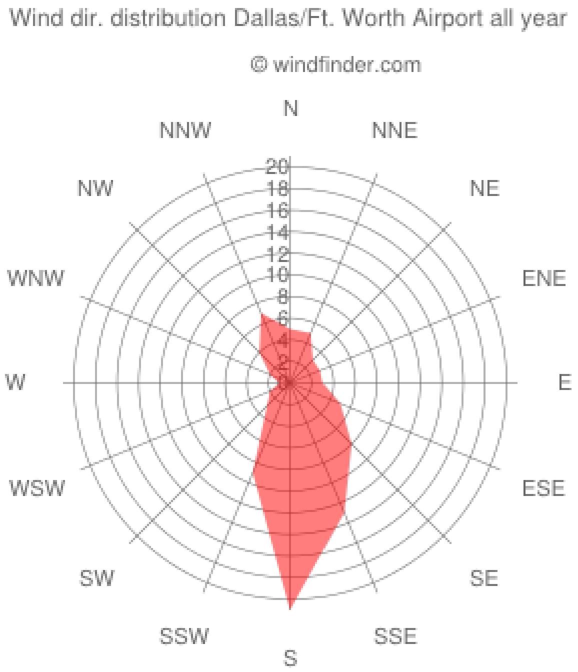

Figure 2.13 Wind Direction Distribution (Wind Finder, 2013)

The seasonal summer wind in Dallas, Texas, comes from the south. But in July 2011, during the drought and heat wave, “light southerly to southeasterly winds of about 2.1 m s-1 advect the warm temperatures towards the northwest, leading to a slight northwest shift of the metropolitan heat island (see figure 2.13). Cooling in the southern part of the metroplex is caused by cold air advection from larger lakes…” (Winguth and Kelp, 2013, p.18).

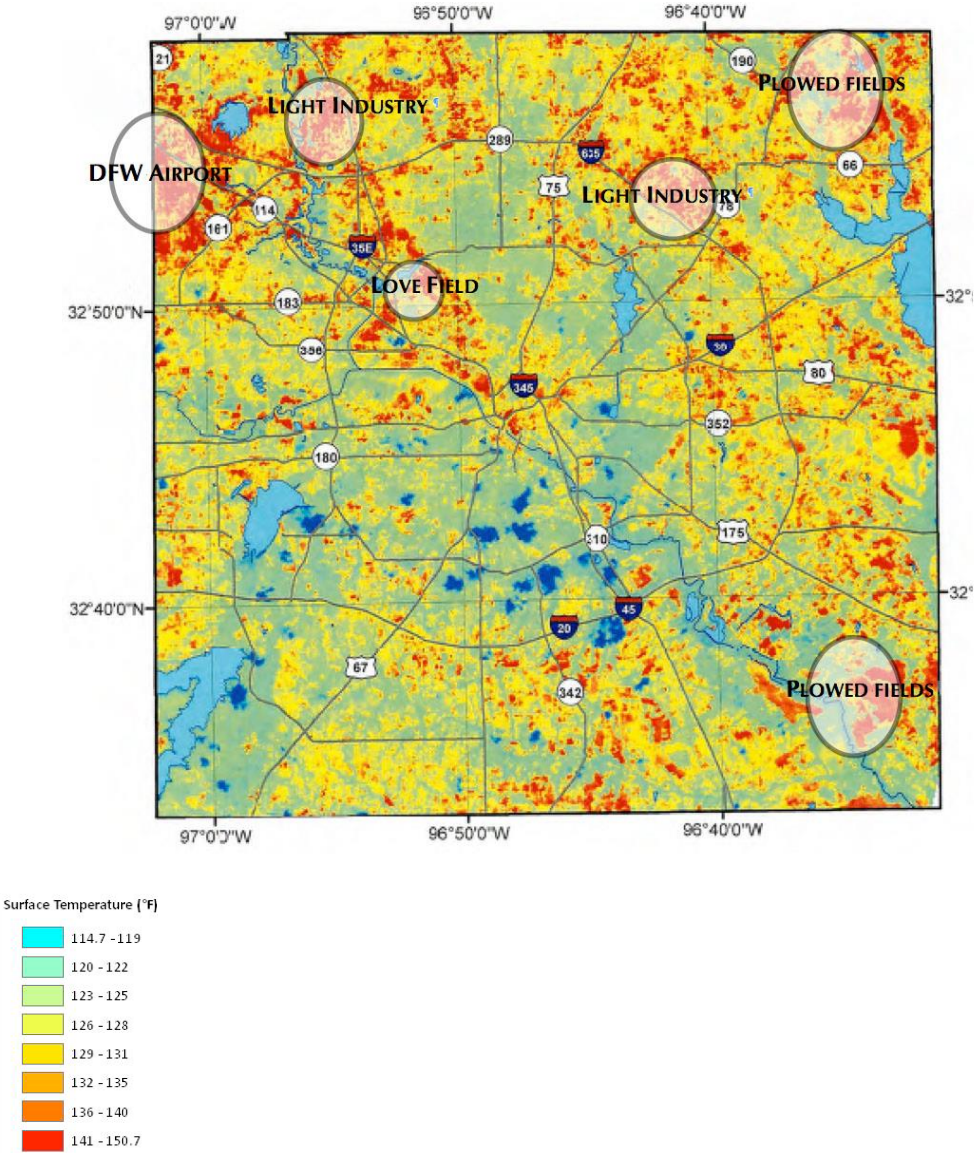

Figure 2.14 Dallas surface temperatures (HARC and EPA, 2009)

This thermal image of Dallas County surface temperatures (figure 2.14), was developed from the 2006 ASTER satellite imagery. The hotter surfaces, shown in red, range upwards above one hundred and fifty degree Fahrenheit. The light blue-green areas are cooler, more vegetated areas, as seen along the Trinity River Basin. The dark blue areas are cloud coverage that was present at the time the images were taken (HARC and EPA, 2009).

The urban heat island effects not only affects an increase of temperatures, but also rainfall locations and patterns, wind flow, and moisture levels. Urban heat island effects are caused by the way cities are built, the materials used, and the surfaces implemented within the cities. By changing urban surfaces, this effect can be reduced. Some of the options to achieve this are:

- Trees: Significantly increase tree cover and vegetation to provide shade and natural cooling thorough evapotranspiration.
- Cool roofs: Either the use of roof surfaces that reduce heat absorption through higher reflectivity or by implementing green roofs.
- Cool pavements: The use of pavement materials that are more reflective or that minimize impervious surfaces (HARC and EPA, 2009, p. 6).

2.3.5 Recent Research in Urban Heat Island Effects

In the urban environment the temperature increases because of the dark and impervious surfaces such as asphalt roads and roofs. Usually the downtown area of a city that has high-rise buildings and high-density becomes warmer than the surrounding areas (Bass et al., 2002). Dallas's climate is categorized as humid subtropical, with eight months of the year having a temperature above sixty eight degrees Fahrenheit with dry winters (Winguth and Kelp, 2013). The urban heat island effect can be reduced by increasing albedo, or by applying more vegetation cover with sufficient soil moisture for evapotranspiration (Bass et al., 2002). Following table illustrates some of the most recent research published on the topic with their emphasis areas.

Table 2.4 Urban Heat Island Effects Literature Review Matrix

Author (s)	Article Title	Date of Publication	Category or Emphasis
Thani et al.	Modification of Urban Temperature in Hot-Humid Climate through Landscape Design Approach: A review	2012	Mitigation strategies to reduce the urban heat island effects
Kleerekoper et al.	How to make a city climate-proof, addressing the urban heat island effects	2011	Causes of urban heat island effects
Alexandri and Jones	Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates	2006	Potential of green walls and roofs to lower urban temperatures
Dimoudi et al.	Investigation of urban microclimate parameters in an urban center	2013	Wind and thermal studies for urban microclimate
Winguth and Kelp	The Urban Heat Island of the North-Central Texas Region and its Relation to the 2011 Severe Texas Drought	2013	Seasonal changes in temperature and effects in Dallas, Texas.
Santamouris	Cooling the cities - A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments	2012	Increasing the albedo of cities and use of vegetation to reduce the urban heat island
Bouyer et al.	Microclimate coupling as a solution to improve building energy simulation in an urban context	2011	Assessment of the microclimate effect on the building energy consumption
Dimoudi and Nikolopoulou	Vegetation in the urban environment: microclimatic analysis and benefits	2003	Microclimate and environmental performance
Sanchez and Alvarez	Modelling microclimate in urban environments and assessing its influence on the performance of surrounding buildings	2004	The relationship between building energy consumption with the wind and sun
HARC and EPA	Dallas Urban Heat Island Dallas Sustainable Skylines Initiative	2009	Emissions reduction and sustainability measurements

2.4 Simulations

2.4.1 Introduction

Simulations are demonstrations of a real-world situation through dynamic relationships (Deming and Swaffield, 2011). They are a method to link visualizations to scientific theories, concepts and values that the researcher already knows (McDermott et al., 2013). In landscape architecture, there are two dynamic models used as a research strategy: process models and simulation models. Landscape process models focus on the function of the landscape such as the biophysical dynamics. Landscape simulation models focus on the way a finished landscape changes with time due to certain conditions and decisions (Deming and Swaffield, 2011). “The primary and subsequent results simply reflect the relationship used in building the model, which in turn, reflect current understandings of the processes” (He, 2008, p. 494). While running a simulation model, some aspects of the interrelationship of the variables can arise that were not anticipated. It can also serve as a tool to build a hypothesis for the future conditions (Deming and Swaffield, 2011). There are three types of landscape simulations models reviewed for this research: simulated environments, computer simulations and field experiments. After a careful evaluation simulated environments was found to be the method adopted for its appropriateness for the research. Following portion briefly reviews each of these techniques as well as their potential strengths and weaknesses.

2.4.2 Simulated Environments

Simulated environments are experimental procedures that serve as a tool to visualize, in two and three dimensions, different phenomena in a model. “The dynamics of real-world interrelationships through a model and uses this to create new knowledge” (Deming and Swaffield, 2011, p. 104). By doing simulated environments, there is a link between the information read and the visualizations, giving empirical information to make design decisions based on the results. The process is straightforward and the scenario can be tested various times with different variables (McDermott et al., 2013). The simulated environments used for this research were wind and sun studies. By running the simulations, the information previously studied becomes tangible and helps the researcher make better informed decisions about the hypothesis (see figure 2.15). The method is known since the process is recorded and visualized.

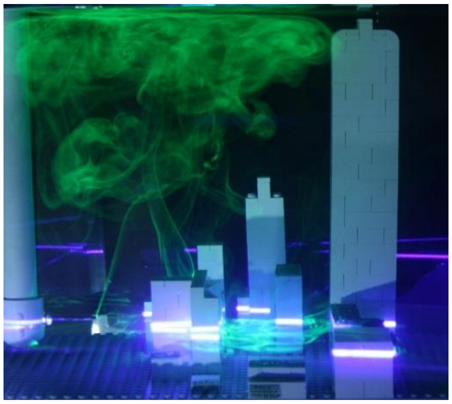

Figure 2.15 Example of a Simulated Environment

2.4.3 Computer Simulations

Computer simulations are a tool to observe characteristics in a specific building or set of buildings such as solar studies, wind studies and energy studies. While doing computer simulations, the user obtains results but is not able to see the process of the data analysis. There are a number of different programs available for computer simulations such as Autodesk Vasari, Sketch Up and etc. (see figure 2.16)

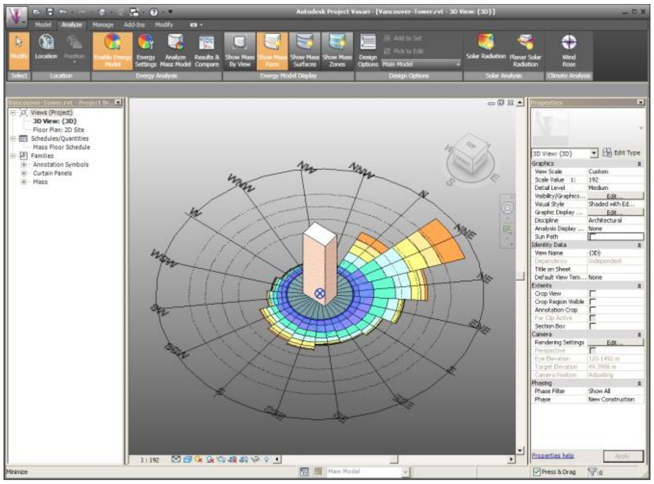

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Figure 2.16 Example of a Computer Simulation with Autodesk Vasari

2.4.4 Field Experiments

Field experiments are experimental procedures in a real-world environment. In landscape architecture, field experiments are typically about the establishments and management of plants and other landscape materials (Deming and Swaffield, 2011). Usually, when doing this type of experiment to avoid natural differences in field conditions, “the research design includes trials across a number of different locations within the study site” (Deming and Swaffield, 2011, p. 119) (see figure 2.17).

Figure 2.17 Example of Field Experiment (UTA, 2008)

2.5 Summary

The use of green roofs and green walls as part of urban green infrastructures in buildings, in the cities, are ways to improve and impact the urban heat island effects and microclimate created in the downtown area. Downtown Dallas has a high index of urban heat island effect and, by implementing green walls and roofs, these effects can likely to be reduced. The urban heat island effect is a problem that most of the cities in the world have to face and, by doing something about it, it can be beneficial to the city and its population. This chapter reviewed literature about green walls and roofs, urban heat island effects in general and in Dallas, Texas, microclimate and their relation to urban form, as well as research methods particularly simulations to such topics. The following chapter focuses on the methods adopted for this research.

Chapter 3

Methodology

3.1 Introduction

This chapter focuses on the methodology used to conduct the research outlined in the earlier chapters. This research uses primarily empirical data to draw findings and results concerning the impact of green roofs and walls on urban heath island effect. Sun and wind studies are performed on two physical models to simulate a portion of the Main Street District in Downtown Dallas. A series of photographs are taken in order to get the first set of results. Then, results are captured through images, later reviewed systematically through graphs, descriptive statistics, and explanatory narratives.

3.2 Research Design

According to Deming and Swaffield (2011), “simulations are representations of selected features or characteristics of a real-world situation. Simulation is differentiated from static representation and predictive modeling by a focus in dynamic relationship” (Deming and Swaffield, 2011, p.103). While exploring the methods to use for studying the impact of green walls and roofs, a simulation was pursued to be an important element to visualize the urban change when green walls and roof are applied to the buildings. The strategies used in the research include: explore, forecast, testing, and learning (Deming and Swaffield, 2011).

Two critical variables, sun and wind, impacting microclimate and plant life are chosen to study the impact of green walls and roofs on urban heath island effect. This research specifically focus on a section of the central business district of Dallas, Texas to study the impact of green walls and roofs. Two physical models were generated to simulate a portion of Downtown Dallas. Sun and air movement studies were conducted on the models. Water Tank, Shallow Water Table, and Heliodon experimental techniques were used to study and visualize a range of scenarios (McDermott et al., 2013). After all the simulations were conducted, an analysis of the photographs and videos was realized, comparing and contrasting it with the literature review studied. Outcomes are documented photographically, data are compared through the photographs with the before and after scenarios. A series of graphs were presented with the findings. Conclusions were drawn from the compiled information. (See figure 3.1).

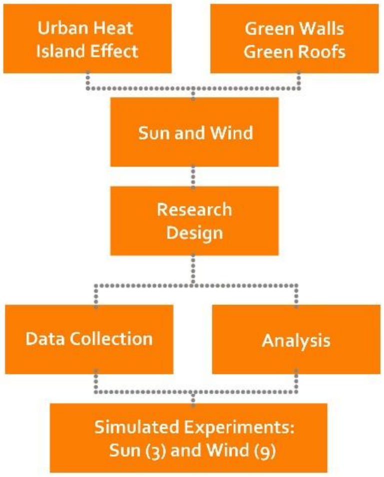


Figure 3.1 Flow Chart Diagram of Analysis Procedure

Following detailed experiment questions are set forth to be answered by this research.

3.3 Experiment Questions

1. The sun pattern influence in downtown Dallas, Texas, without green walls and roofs and when adding green walls and roofs.
2. The seasonal summer wind influence in a pedestrian level in downtown Dallas, Texas, without green walls and roofs and when adding green walls and roofs.
3. The seasonal summer wind influence in downtown Dallas, Texas, without green walls and roofs and when adding green walls and roofs.

4. The seasonal summer wind influence in a building without green walls and roofs and when adding green walls and roofs.

3.4 Study Area: Dallas, Texas

Dallas, Texas was chosen because of the proximity, urban density and form, and the importance in the North Central Texas area. The area of study had to be one where the urban climate was clearly different than the rural, “A study of Dallas and Houston found that urban summer nighttime temperatures (atmospheric) were almost 4ºF warmer than rural temperatures (averaged over 2000 to 2006). The greatest differences occurred around 6 a.m. During the day, urban temperatures averaged almost 2ºF warmer. The same study showed that the Dallas daytime heat island was more evident than Houston’s” (HARC and EPA, 2009, p. 1). There is a need to mitigate the urban heat island effects in downtown Dallas.

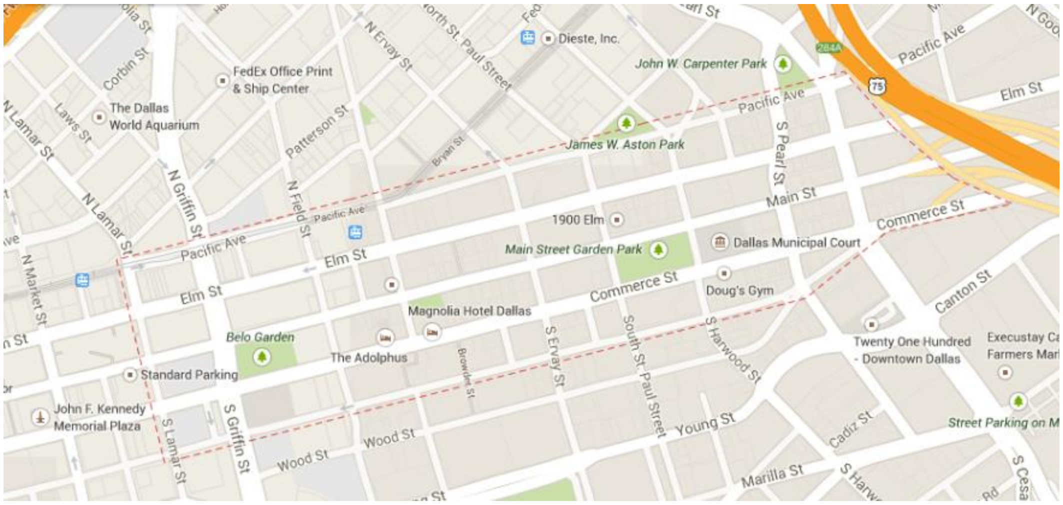


Figure 3.2 Map of the Main Street District (Map Adopted from: Google Maps, 2013)

In order to make the experiments possible, a study of the different areas in downtown Dallas was conducted and, with the information obtained, the area was chosen. The Main Street District had the specific characteristics the researcher was looking for in a downtown area (see figure 3.2, 3.3, 3.4):

1. Typical downtown urban blocks
2. Combination of historic buildings with new buildings
3. Combination of high rise buildings and pedestrian scale buildings
4. Balance of open spaces (parks, parking lots, plazas), and built spaces

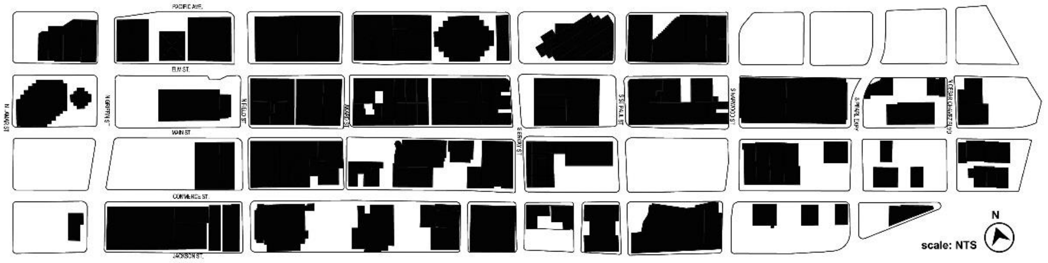


Figure 3.3 The Main Street District Figure Ground

Figure 3.4 The Main Street District Survey

After choosing the Main Street District as the area to be studied, a survey of green walls and roofs was done within the area (see figure 3.5). Then, in order to make the experiments, two models were created, one of a big portion of the Main Street District and the second one of a smaller portion.

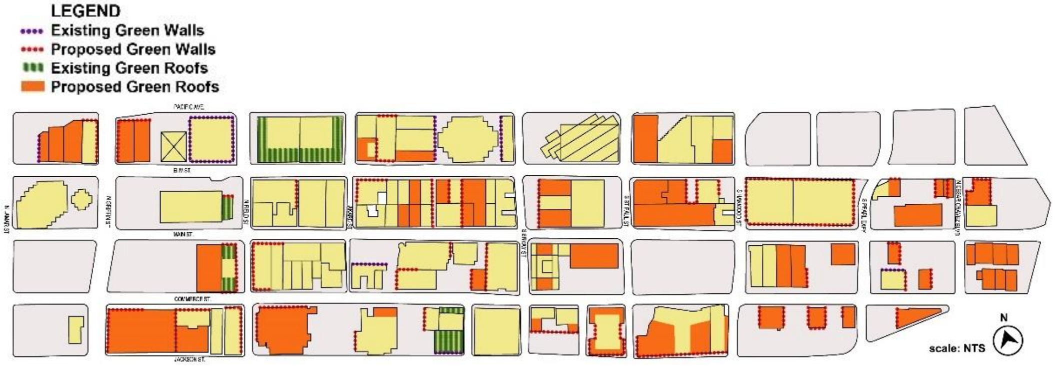


Figure 3.5 Green Walls and Roofs - Existing and Added

Figure 3.6 Green Wall at Magnolia Hotel, Dallas, TX

Figure 3.7 Green Wall at 2107 Main St., Dallas, TX.

Figure 3.8 Green Wall at 2211 Commerce St., Dallas, TX.

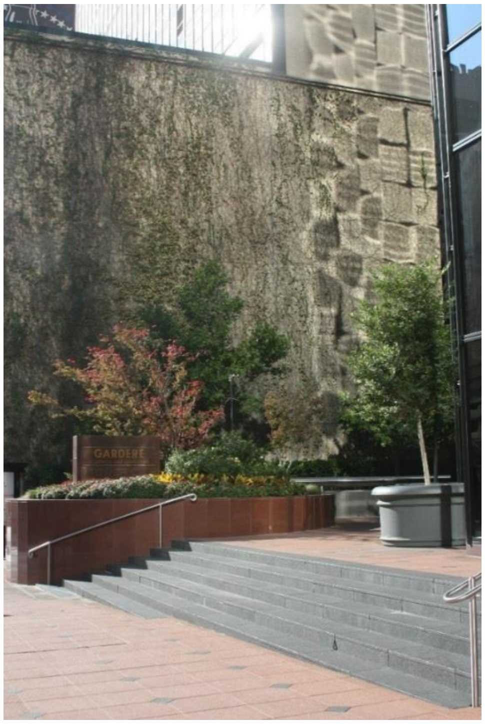


Figure 3.9 Green Wall at Gardere Tower Club, Dallas, TX.

Figure 3.10 Green Wall at the Renaissance Tower, Dallas, TX.

Figure 3.11 Green Wall at 909 Elm Street, Dallas, TX.

Figure 3.12 Green Wall at 1514 Commerce Street, Dallas, TX.

3.5 Data Collection

The data collected for this research included three approaches: A combination of GIS observation and Google Earth images, an on-site survey, and the available city data. The data were mainly obtained from GIS, Google Earth, and the on-site survey. The data were compared between each other to obtain an updated map of the area in order to make the best decisions on the placement of the green walls and roofs. The steps taken before data collection were:

1. Literature review and synthesis in order to study the concept and impact of green walls, green roofs, urban heat island effects, urban heat island effects in downtown Dallas, and the impact that green walls and roofs can have in the urban heat island.
2. Designing the simulation physical experiments and then performing them.
3. Performing the computer generated simulation.
4. Comparing the data obtained from simulations, and then collecting and consolidating the results.

3.5.1 Sun Studies

Heliodon is one of the oldest devices for simulating daylight and its shadows (McDermott et al. 2013). A simulated sun and shadow pattern is possible using an incandescent light representing the sun in different months and times of the day. A model is placed in a rotating table and adjusted to the coordinates of the specific place. The incandescent light is then placed on a pole and the height of it varies depending on the month. The table rotates to set up the time of the day. Two sets of pictures and videos were taken in each date. One set with the model with green walls and roofs, and the other one without.

Three months daylight and shadows were recorded:

- December 21: six am to eight pm every two hours
- March 21: six am to eight pm every two hours
- June 21: six am to eight pm every two hours

3.5.2 Wind Studies

To study the wind, two apparatus were used, a Shallow Water Table and a Water Tank. Open and closed water flumes have been used to study flowing water (aqueous flow) in open and closed channels for at least as long as modern wind tunnels have existed. In this context, science defines air as a "fluid" (McDermott et al. 2013). The water in the Shallow Water Table is about two inches deep and the wind pattern can be visualized on a pedestrian level. On the other hand, the PLIF is a fifteen gallon tank used to visualize the wind pattern in three-dimensions; fluorescing fluids are injected through a needle attached to a vertical tube and gravity makes the fluid move in a horizontal line. "This deeper tank is used to investigate simulated flow patterns about urban and building forms and landscape designs" (McDermott et al. 2013, p. 3).

3.6 Instruments and Materials

3.6.1 Instruments of Simulated Experiments

The simulation experiments were completed using the following instruments:

1. Heliodon
    a) Angle adjustable incandescent light
    b) A vertical stand where the light source is placed according to a specific date of the year
    c) "iPhone" digital camera
    d) An angle adjustable rotating base for models
2. Shallow Water Table
    a) Shallow tank with a variable velocity recirculating pump and a self-contained water source (McDermott et al., 2013)
    b) Opaque vegetable dyes injected through a syringe
    c) A camera connected to a computer to take video

3. Water Tank
    a) Fifteen gallon tank
    b) Fluorescing fluids
    c) Fluorescing fluid feed tube with a plume
    d) Modified laser pointers
    e) Camera
    f) Mirror

3.6.2 Materials for Physical Models

A pilot study of materials was made in order to decide on the best materials to produce the models:

1. Modeling clay
2. Plastic blocks “Lego”
3. Wood
4. Acrylic

“Lego” and modeling clay were the materials chosen to create the models. The modeling clay was used to develop the largest area of the Main Street District. “Lego” was the materials used to create the small study area in the Main Street District.

A pilot study of materials to represent the green walls was conducted:

1. Silver aluminum screen
2. Black aluminum screen
3. Black aluminum screen modified with spray paint

The material chosen to represent the green walls was black aluminum screen with green spray paint and for the single building clump foliage was added.

A pilot study of materials to represent the green roofs was conducted:

1. A sponge was cut in half width length
2. A black aluminum screen painted with spray paint

The material chosen to represent the green roofs was black aluminum screen with green spray paint and for the single building clump foliage was added.

A base of half an inch acrylic was used for the clay model. A base of “Lego” was used for the “Lego” model.

3.6.3 Software Packages for Computer Modeling

The programs used to create the computer model are as follow, in order:

1. Shape files were obtained and adapted to the specific area of study in GIS (Geographic Information Systems).
2. The GIS file was then exported to AutoCAD as a JPG and then traced on top of it to create the buildings footprints as well as the blocks of the Main Street District.
3. The file was then exported to Sketch Up to create the 3D model.

3.7 Data Analysis

3.7.1 Sun Studies

The Heliodon simulation was conducted in two steps. First set was conducted with the “Lego” model without any green walls and roofs. Data were analyzed by putting the images of each day of each month studied side by side to conclude which month has the most daylight hours and on what part of the buildings the sun is lighting the most. After analyzing December twenty-one, March twenty-one, and June twenty-one, conclusions were made. The second set of studies was conducted with the “Lego” model, with the existing and added green walls and roofs. The same procedure was made as with the first set.

3.7.2 Wind Studies

The wind studies were divided into two simulated environments the PLIF and the Shallow Water Table. Each one was studied before and after the green walls and roofs were added. The Shallow Water Table was conducted using the modeling clay model, and summer seasonal winds were tested coming from the south. The wind was represented with a black vegetable dye that was injected on the south side of the model, between the streets and open spaces. A series of videos were taken and then data were analyzed to gain an understanding how the wind flows in this particular region in a pedestrian level. The same process was followed for the model with green walls and roofs.

The PLIF was conducted using a portion of the “Lego” model, and summer seasonal winds were tested coming from the south. The wind was represented with fluorescing shooting from the south part of the model and was placed between two streets. A series of pictures were taken of the whole apparatus, the tank itself, and the mirror itself. The pictures provided information in three-dimensions. After each series of simulations were tested with the same characteristics, an analysis of data, on how the wind flowed and where it creates vortices, was completed and then compared to find their conclusions. Another set of PLIF simulations were conducted using one building made of “Lego” to analyze in a bigger scale how the wind acts in a building with no green wall or roof, how it reacts in a building with a green roof, a building with a double-skin green wall, a building with a green wall attached to the building, and a building with a green roof and green wall attached to it. Data were then analyzed and results were obtained.

3.8 Simulated Experiment Procedures

Starting with a map of downtown Dallas, a selection of the area was made by looking into GIS data and Google Earth images. Then a map was extracted from GIS of the selected area (Main Street District) and taken to AutoCAD to create a base map of the blocks and buildings footprints. When the base map was ready it was then exported to Sketch Up to create a 3D model in order to make the physical model possible.

As part of the experimental simulation, the first part of the experiments consisted a pilot study of the materials. First, research of the different possible materials was done in order to decide on the best ones to use to produce the physical models. The main characteristic the model had to have, was the ability to be submerge in water in order to conduct the Water Tank and the Shallow Water Table simulation where the seasonal wind can be tested. Second, a pilot study of the selected materials was made under water with the Planar Laser Flow: “Lego”, acrylic, clay, and wood (See Appendix A). Third, a pilot study of three different screens simulating a green wall was done under water with the Planar Laser Flow: silver aluminum screen, black aluminum screen, black aluminum screen with spray paint (See Appendix A). Forth, a pilot study of the selected materials with the aluminum screen in front was made under water with the Planar Laser Flow: Lego, acrylic, clay, and wood (See Appendix A). After selecting the materials and deciding on the best material to use for the small section of the Main Street District to be studied, a two by two inch “Lego” cube was made with a sponge on top to simulate a green roof under water with the Planar Laser Flow (See Appendix A).

The first rounds of experiments were done after testing the different materials. First, a Heliodon experiment was done to a Lego physical model (scale 1”=100’) of the small section of the Main Street District, to study the sun pattern in downtown Dallas and also to visualize the shading effects of the buildings in order to decide where to place green walls and roofs (See Appendix B). Then, a Shallow Water Table experiment was done to a clay physical model (scale 1”=120’) of the larger section of the Main Street District, to study the impact of the wind in buildings without any green wall or roof (See

Appendix C). After that, the Water Tank experiment was done using to a “Lego” physical model (scale 1”=100’) of a smaller section of the Main Street District, to study the impact of the wind in buildings without any green walls and roofs, (See Appendix D).

The second round of simulations were done after analyzing the first round of studies and after choosing which buildings were going to be added with green walls and roofs. First, a Heliodon experiment was done with the “Lego” physical model (scale 1”=100’), of the small section of the Main Street District, to study the sun pattern in downtown Dallas and also to visualize the shading effects of the buildings when green walls and roofs are placed (See Appendix B). Second, a Shallow Water Table experiment was done to a clay physical model (scale 1”=120’) of the larger section of the Main Street District, to study the impact of the wind in buildings when green walls or roofs are placed, (See Appendix C). Third, a Water Tank experiment was done to a Lego physical model (scale 1”=100’) of a smaller section of the Main Street District, to study the impact of the wind on buildings with green walls and roofs, (See Appendix D). Fourth, a Water Tank experiment was done to a Lego physical model (scale to define) of one building within the Main Street District, to study in a larger scale the impact of the wind on a building with a green wall, (See Appendix D). Fifth, a Water Tank experiment was done to a Lego physical model (scale to define) of one building within the Main Street District, to study in a larger scale the impact of the wind on a building with a green roof (See Appendix D). The sixth and last experiment was a Water Tank simulation, done to a Lego physical model (scale to define) of one building within the Main Street District, to study in a larger scale the impact of the wind on a building with a green wall and roof (See Appendix D).

After all the simulations were conducted, an analysis of the photographs and videos was realized, comparing and contrasting it with the literature review studied. A series of graphs were presented with the findings. Conclusions were drawn from the compiled information.

3.9 Methodological Limitations

This research is a simulated exploration of how green walls and roofs influence the urban heat island effects. Downtown Dallas was chosen as the study area in order to have full access to the physical evidence. The methodology utilized was a series of simulated environments in order to obtain and understand the information while physically looking at it. Some of the simulations were insignificant for the process of this research but the practice of doing the experiment simulations helped the researcher have a better understanding of the process and the information. The use of simulated environments can have their own limitations, the size and function of the apparatus determines the size, scale and materials of the physical models. As each simulation was conducted, even though the placement of the apparatus was marked the camera or the model had a difference making it hard to compare. Due to time limitations, it was not possible to conduct multiple simulations to test different materials, conditions, and/or scenarios. Therefore this research is limited in content. The placement of green walls and roofs in experiments as part of the simulated environments was to develop scenarios to obtain data and visualize potential impact of these green infrastructure elements in the urban microclimate, not as a suggestion of placement.

The methods suggested in this research are a combination of, a survey of the green walls and roofs of the area and simulated environments using physical models. During the process of doing the simulations, additional variables came into focus and could be part of a further study.

3.10 Bias and Errors

Since the researcher is the primary instrument for data collection and analysis, it is subject to human bias and errors. While deciding on the materials to use for the physical models, the decision on which materials to use was based on the results obtained from the pilot study of materials, as well as availability, cost and time required to model. It was hard to represent green walls and roofs due to scale, availability and time. Three materials were tested to decide on the most convenient due to scale, time, cost, and production. The material chosen to represent green roof and walls was a window screen with green spray paint, since the screen is porous, it was impossible to replicate the same screen for each building

The last set of PLIF experiments in the single building was conducted to visualize in a bigger scale how the wind reacts when a green wall and green roof are added. The material used to represent the green wall and roof is the same painted screen which means the scale of that did not change even though the scale of the building did. However, a clump foliage was added to the screen to visualize the plants in a green wall or roof. For the single building simulation the green wall was moved into two positions and the clump foliage changed because of the water. The modeling clay is moldable and, because of that property, the shape of the model changed every time it was used due to temperature or touch. The velocity of the fluorescing could not be controlled which made every PLIF simulation different in some way. The lasers used to illuminate the fluorescence in the PLIF simulation could vary in brightness depending on the battery life. For the PLIF simulations with models that had green walls and roofs, a flash light was used in order to visualize them, which made the before and after pictures (before and after green walls and roofs were added) look different. For the Shallow Water Table, the quality of the videos depended on the amount of vegetable dye added, which was hard to manipulate and to set at the exact same place, distance and quantity. For the Heliodon simulation, pictures and videos where captured of each day of the studied month. Since the table is routable, there is a variation in the time and speed of each video.

It is important to consider that the researcher completed this study as a fulfillment of the requirements for a master's degree in Landscape Architecture and does not have a bias towards urban heat island effects, green walls or roofs, which should not be taken into consideration in evaluating the results and implications in the following two chapters.

3.11 Summary

This research uses primarily empirical data to draw findings and results concerning the impact of green roofs and walls on urban heath island effect. Sun and wind studies are performed on physical models to simulate a portion of the Main Street District in Downtown Dallas. Pictures are taken, compared, and analyze to obtain results. This chapter reviewed the methodology used for this research. The following chapter focuses on the analysis and findings of this research.

Chapter 4

Analysis and Findings

4.1 Introduction

This chapter presents the analysis and findings of the research which were conducted to study the impact of green walls and roofs in the urban microclimate, and their influence in alleviating the urban heat island effects in downtown Dallas, Texas. The chapter begins with an overview of the materials tested to conduct the simulations. Then the chapter is divided into the two types of simulations: wind and sun studies. The information is analyzed using the photographs taken and then a comparison of the models in each situation is made.

Each of the experimental questions is answered relating the information analyze from the photographs. First, the objective was to answer four experimental questions: (1) the sun pattern influence in downtown Dallas, Texas without green walls and roofs and when adding green walls and roofs, (2) the seasonal summer wind influence in a pedestrian level in downtown Dallas, Texas without green walls and roofs and when adding green walls and roofs, (3) the seasonal summer wind influence in downtown Dallas, Texas without green walls and roofs and when adding green walls and roofs, (4) the seasonal summer wind influence on a building without green walls and roofs and when adding green walls and roofs. Second, the research questions were answered comparing the experimental questions results to the literature review; research questions: (1) can green walls and roofs help reduce the urban heat island effect in an urban dense area such as downtown Dallas?, (2) can green walls and roofs influence the seasonal wind patterns to alleviate urban heat island effect in downtown Dallas?, (3) can green walls and roofs influence the solar exposure of buildings and districts to alleviate urban heat island effect in downtown Dallas?

4.2 Testing the Materials and Equipment

A study of different materials was conducted to simulate interactions between materials and environment for the Water Tank using Laser Induced Fluorescence (LIF) and Planar Laser Induced Fluorescence (PLIF), two sets were studied. The characteristics needed for the materials were, first, to be able to submerge the materials in water, second, to be fast and easy for the model production, third, a smooth material with softness on the surface, fourth, a material that allow to be replicable, fifth, scale accuracy, six, a material that could show how the wind changes its pattern when it hits a 'building'. The first sets of studies were conducted using four different materials and looking for the wind reaction when hitting the surface. Materials are chosen to represent buildings. The second sets of studies were conducted to the same four materials but adding a two by two inch aluminum screen in front of each material. Aluminum screen in this case was used to represent green walls and/or roofs. The aluminum screen was used as a porous proxy for a green wall.

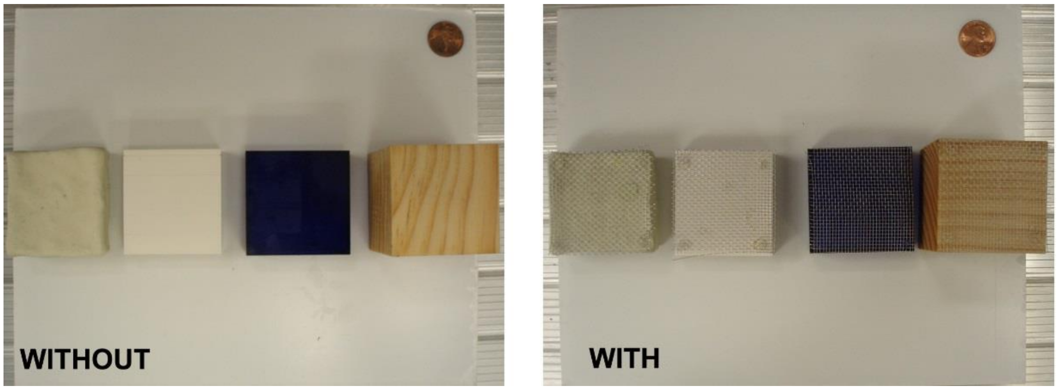


Figure 4.1 Materials in order from left to right: modeling clay, "Lego", acrylic block, wood block

The order of the materials and the results are as follow:

1. A two inch long, two inch wide, by half an inch depth piece of interlocking plastic blocks (Lego) was tested. The test showed that when the wind (fluorescing) hits the “Lego”, it moves vertically in the building surface and creates a vortex that turns back into the block. The vortex in the upper part was stronger than in the down part (see figure 4.2).

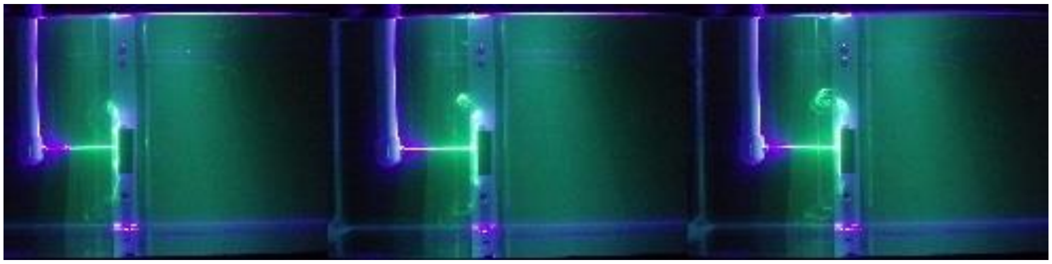


Figure 4.2 Building Model ("Lego") 2"x2"x1/2"

A two inch long, two inch wide, by half an inch depth piece of “Lego” was tested with a two by two inch aluminum screen in front. The test showed that, when the wind (fluorescence) hits the block, the screen provokes the fluid to bounce out of the surface and revolve close to it, creating vortices and, at some point, moving out of the surface and up (see figure 4.3).

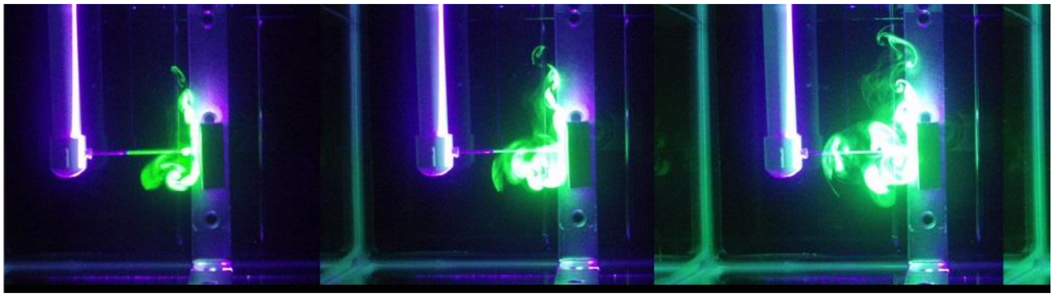


Figure 4.3 Building Model ("Lego") 2"x2"x1/2" with Screen

2. A two inch long, two inch wide, by half an inch depth piece of an acrylic block was tested. The test showed that, when the wind (fluorescence) hits the acrylic block, the wind moves vertically in the building surface and, creates a vortex that, turns back

into the block, but the energy stays closer to the acrylic block surface and the vortices are visible (see figure 4.4).

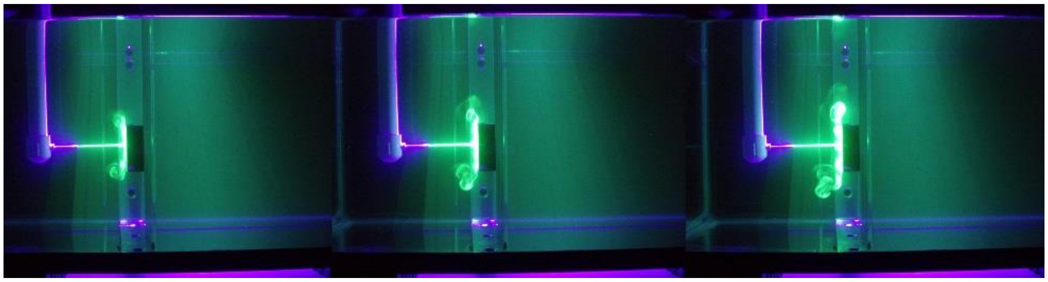


Figure 4.4 Building Model (Acrylic) piece 2"x2"x1/2"

A two inch long, two inch wide, by half an inch depth piece of an acrylic block was tested with a two by two inch aluminum screen in front. The test showed that, when the wind (fluorescence) hits the acrylic block, the wind stays in the block surface and, creates a big vortex that, turns back into the surface, and then moves out and up. All the energy is concentrated in the acrylic block surface (see figure 4.5).

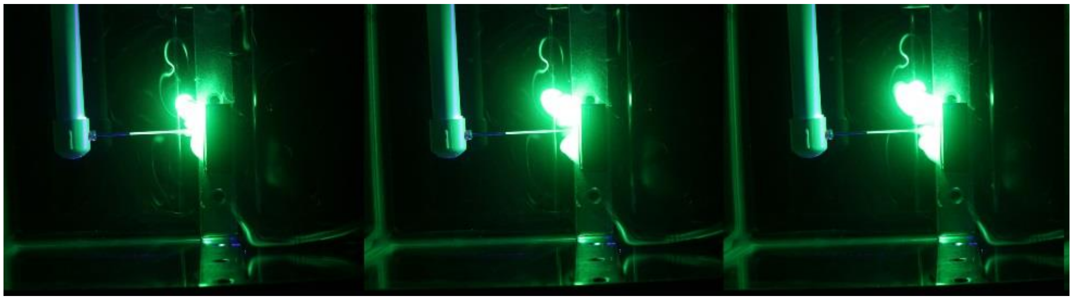


Figure 4.5 Building Model (Acrylic) 2"x2"x1/2" with Screen

3. A two inch long, two inch wide, by half an inch depth piece of modeling clay was tested. The test showed that, when the wind (fluorescing) hits the modeling clay, the wind moves slightly vertical in the block surface and, the vortices are wider creating a lot of energy revolving around in the same place (see figure 4.6).

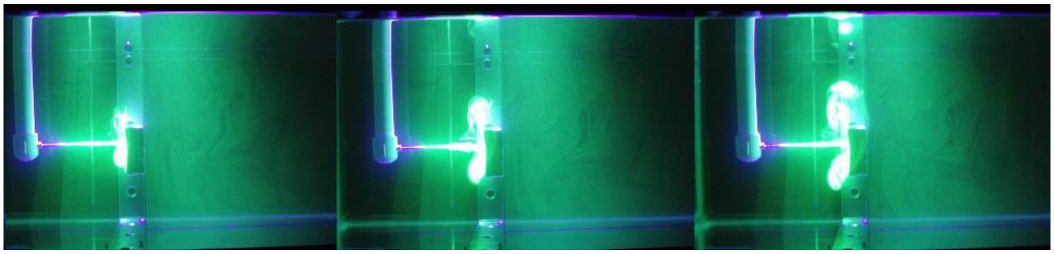


Figure 4.6 Building Model (Modeling Clay) 2"x2"x1/2"

A two inch long, two inch wide, by half an inch depth piece of modeling clay was tested. The test showed that, when the wind (fluorescing) hits the modeling clay, it immediately creates vortices revolving around right in the surface of the block. The vortex in the upper part is stronger than the one in the down side and at some point the upper part vortex moves out of the surface and up (see figure 4.7).

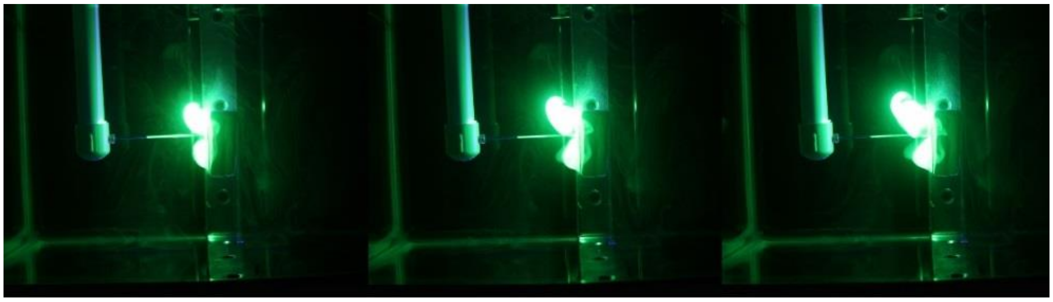


Figure 4.7 Building Model (Modeling Clay) 2"x2"x1/2" with Screen

4. A two inch long, two inch wide, by two inch depth wood cube was tested. The test showed that, when the wind (fluorescence) hits the cube, the fluorescing moves vertically on the surface of the block creating two strong vortices. The vortex on the bottom stays in the surface and the one on the top leaves the surface and comes back (see figure 4.8).

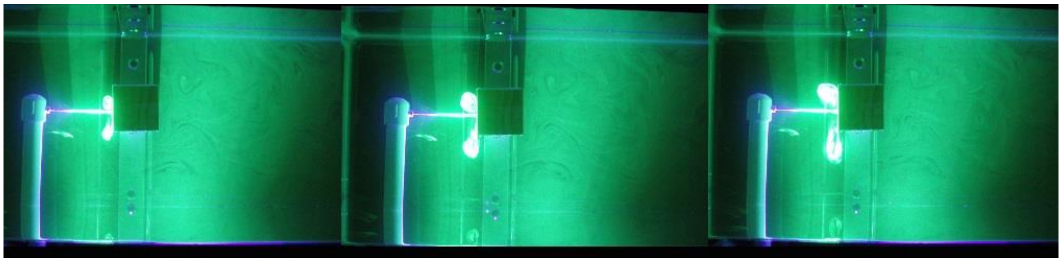


Figure 4.8 Building Model (Wood Cube) 2"x2"x2"

A two inch long, two inch wide, by two inch depth wood cube was tested. The test showed that, when the wind (fluorescence) hits the block, the wind stays on the surface of the cube and slowly travels away from the surface. The fluorescing is concentrated in the upper part of the cube were it is stronger (see figure 4.9).

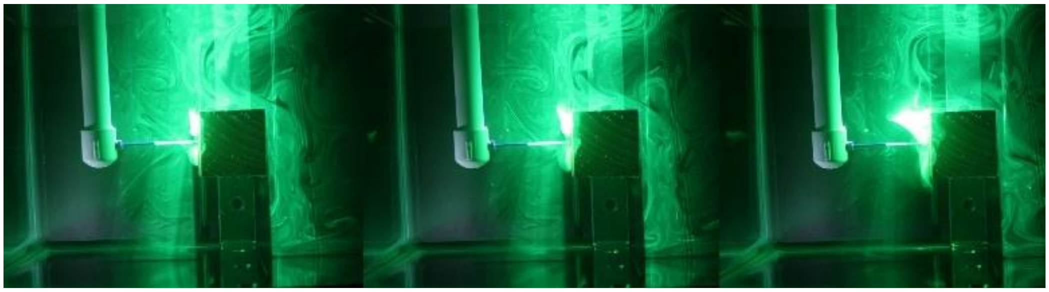


Figure 4.9 Building Model (Wood Cube) 2"x2"x2" with Screen

A study of three different aluminum screens were tested to decide on the one that best demonstrates the conditions of a green wall and roof (see figure 4.10).

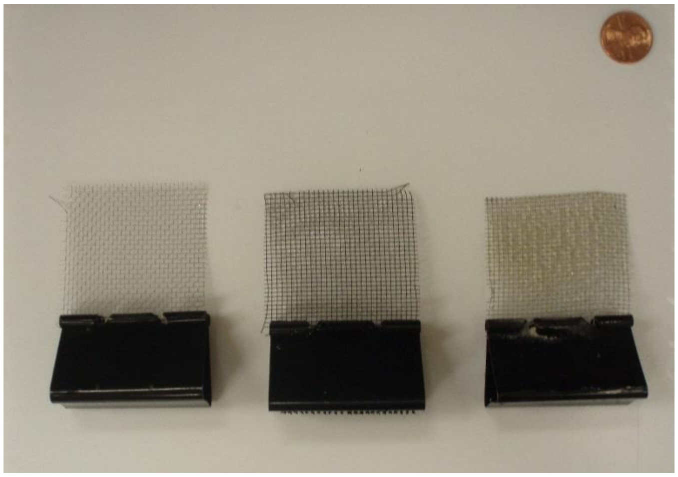


Figure 4.10 Aluminum Screens (Materials in order from left to right: silver screen, black screen, screen with paint)

The study tested two aluminum screens one silver, one black and one with spray paint. The results are as follow:

1. Silver aluminum screen two by two inch with offset grid pattern: The test shows that, when the fluorescing hits the screen part of the fluid bounces out of the surface and the majority flows through. The part of the fluorescing that bounces back develops vortices that revolve in and around the surface and at some point they become larger and move out. The impact of the fluorescing in the screen is good.

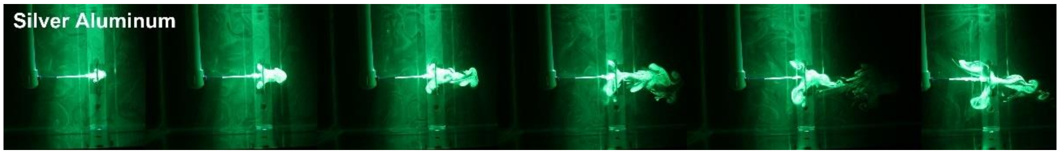


Figure 4.11 Green Wall and Roof (Silver Aluminum Screen)

2. Black aluminum screen two by two inch: The test shows that, when the fluorescing hits the screen, a small quantity of the fluids stays on the surface and the majority flows through. Half way into the test, more fluid bounces out of the surface after

it repeatedly hits the screen and creates small vortices. The impact of the fluorescing and the screen is not strong.

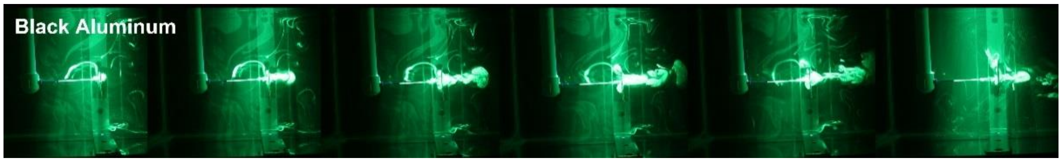


Figure 4.12 Green Wall and Roof (Black Aluminum Screen)

3. Black aluminum screen two by two inch covered with, approximately, sixty five percent spray surface paint. The test shows that, when the fluorescing hits the screen, most of the fluid bounces off the surface and only a little goes through. The fluorescing, when it hits the screen, creates two vortices that rapidly develop into bigger ones. The impact of the fluorescing in this test is evident.

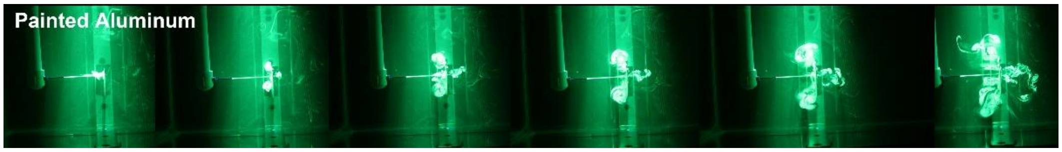


Figure 4.13 Green Wall and Roof (Black Aluminum Screen Painted)

The purposes of testing the materials were to identify which materials work better for the desired studies. After carefully review, the materials chosen for the models were modeling clay and “Lego” because both materials complied with the characteristics previously mentioned, such as durability in the water, scale, smoothness, accessibility, replicable, and etc. The following study conducted was, the Heliodon sun study, which helped dictate and visualize the seasonal sun patterns and the shadows produce by the building, in order to decide where to add green walls and roofs.

4.3 Sun Studies

A series of sun studies were conducted, with a Heliodon apparatus, in order to obtain visual data about, seasonal sun patterns and the shadows produced by the buildings. In this study, the effects of green walls and roofs on buildings cannot be visualize with the shadows but, the amount of sunlight the buildings received can be recorded which, in real life, affects the exterior and interior climate of the buildings. Three dates of the year were documented. For each date, two sets were recorded, one with green walls and roofs and one without green walls and roofs. The model was made with "Lego" and the area of study is a portion of the Main Street District in Dallas, Texas. The scale of the model is 1"=100'. A comparison between the model with green walls and roofs and the model without was made for each date starting at six in the morning and recording the pictures every two hours until eight at night; the results are as follow:

1. March 21 (spring) (see figures 4.14, 4.15): From six am till twelve pm the shadows of the building do not cover other buildings, but starting at two pm the shadows of the buildings become stronger and cover most of the area until the area is dark at eight pm.

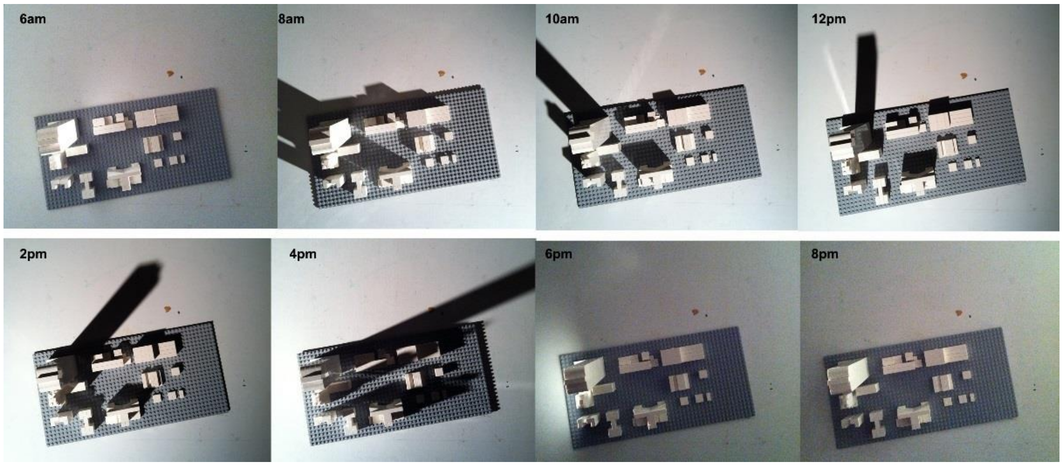


Figure 4.14 Heliodon - March 21 Only Buildings (Small Portion District Model)

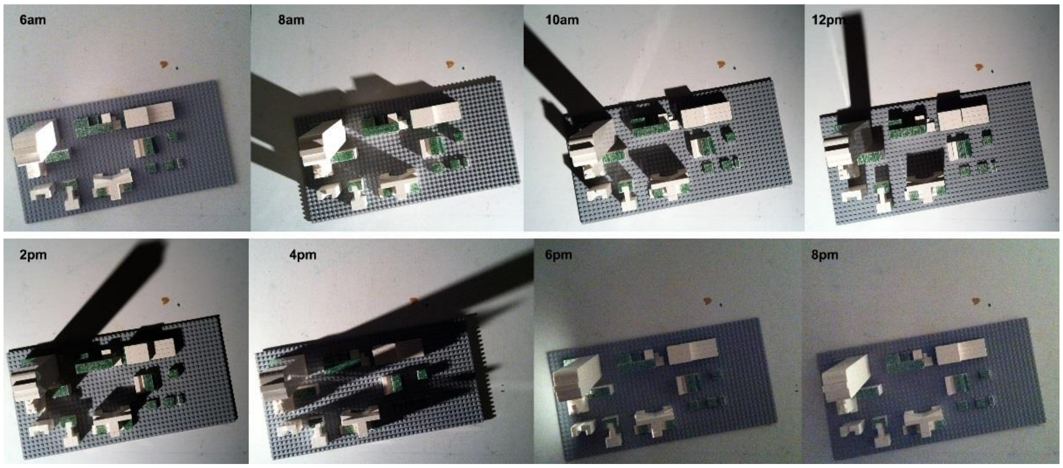


Figure 4.15 Heliodon - March 21 Buildings with Green Walls and Roofs (Small Portion District Model)

2. June 21 (summer) (see figure 4.16, 4.17): From six am till two pm the shadows of the building do not cover other buildings, but starting at four pm the shadows of the buildings become stronger and cover most of the area. There is still some light at eight pm.

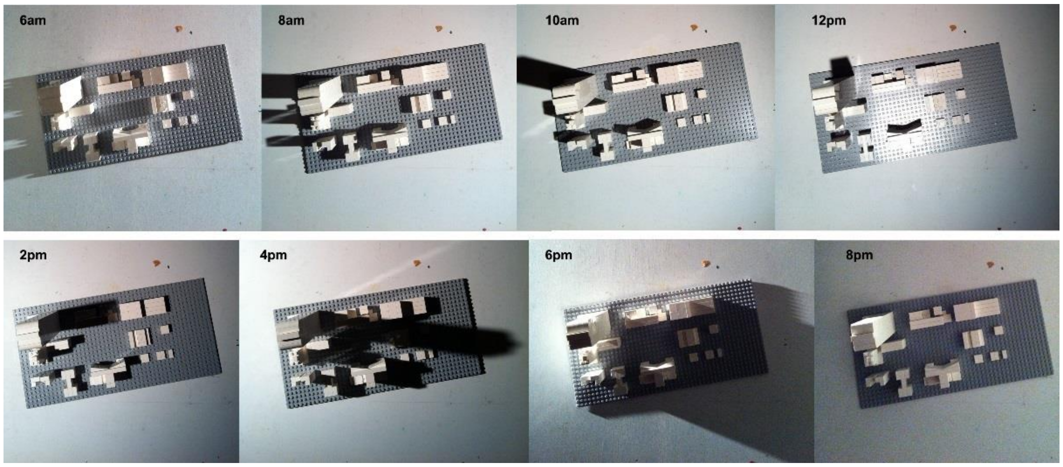


Figure 4.16 Heliodon - June 21 Only Buildings (Small Portion District Model)

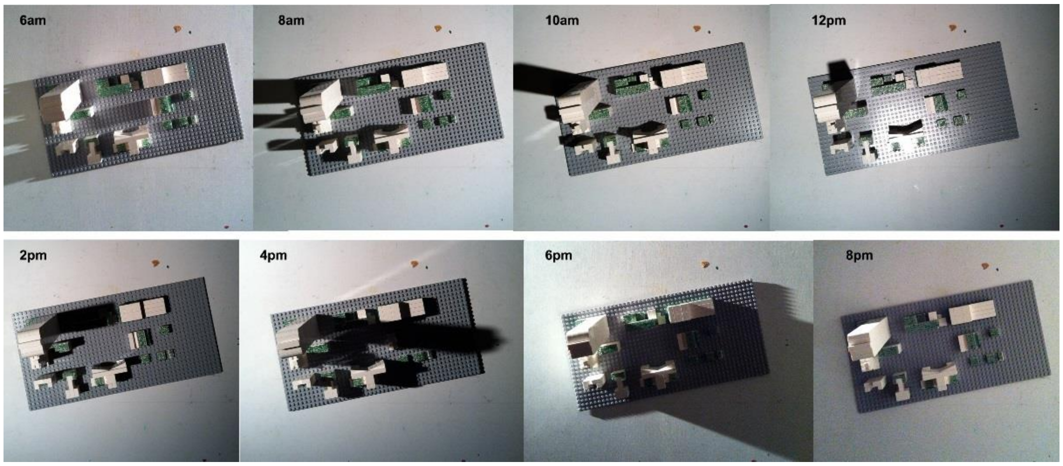


Figure 4.17 Heliodon - June 21 Buildings with Green Walls and Roofs (Small Portion District Model)

3. December 21 (winter) (see figure 4.18, 4.19): During the winter the strongest sunlight can be seen at eight am and by ten am the shadows become stronger. By four pm, the shadows are covering most of the area and by six pm it is almost dark.

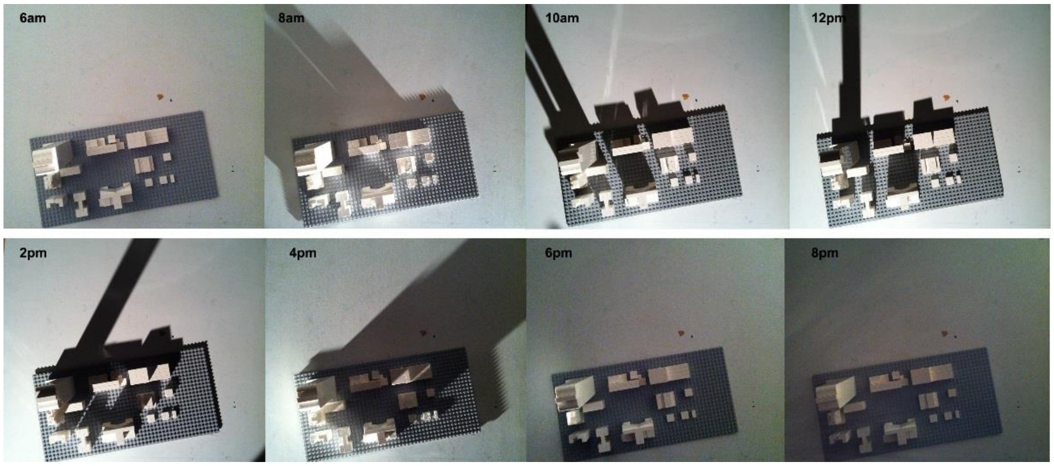


Figure 4.18 Heliodon - December 21 Only Buildings (Small Portion District Model)

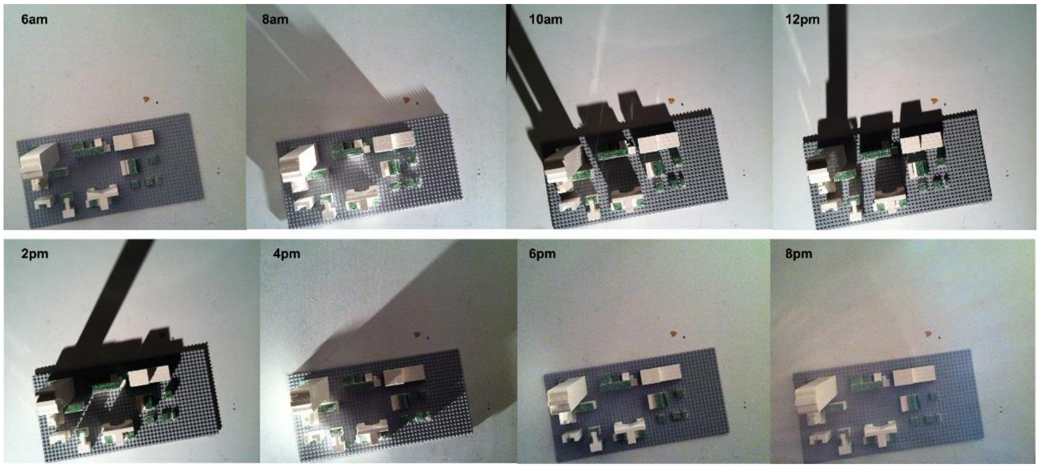


Figure 4.19 Heliodon - December 21 Buildings with Green Roofs and Walls (Small Portion District Model)

When adding green walls and roofs, the buildings that have more exposure to the sun seem to benefit from the application of these green infrastructure elements. The Heliodon study helped the researcher visualize where the simulated sun light hit the buildings in the three seasons. However, the most important season was summer since it is the warmest season with the longest days. On June 21st, the sun appears before six in the morning and disappears after eight o clock at night. From six am to six pm there is almost a full sun exposure to the buildings and by placing green walls and roofs, the buildings will not get as hot inside or outside as a building without green walls and roofs.

As it is highlighted earlier in the literature review, the solar radiation can be mitigated with vegetation because of the shadow produced by the vegetation. “In experimenting with traditional green façades Köhler (2007 & 2008) found that the magnitude of this shadow effect depends on the density of the foliage. Ivy is the species that provides the maximum cooling effect, comparable to the shade of trees. Differences up to three degrees Celsius in indoor temperature during winter were found.” (Köhler, 2007 & 2008 in Perez et al., 2011, p. 4856). Direct sunlight on the façade is filtered by the leaves, and through the phototropism effect, one-hundred percent of the light falls into the leaves, five to thirty percent of that light is reflected, five to twenty percent of that light is used for photosynthesis, ten to fifty percent is transformed into heat, twenty to forty percent is used for evapotranspiration and five to thirty percent is passed through the leaves (Ottele et al., 2011). Recent studies have shown that climbers also provide a cooling effect on the building's surface, even in the hot periods of the year (Perez et al., 2011; Ottele et al., 2011). Green roofs can reduce the energy required for the maintenance of interior climates (Del Barrio, 1998), because vegetation and growing plant media intercept and dissipate solar radiation.

4.4 Wind Studies

A series of wind studies were conducted with two different apparatus. The first one was a Shallow Water Table. It was used to visualize the seasonal summer wind on a pedestrian level and in two-dimensions. For this simulation, a larger portion of the Main Street District in Dallas, Texas was studied. Earlier pilot studies allowed for the selection of the material in this experiment. And therefore modeling clay was used to construct a physical model at an 1"=120' scale. For the second apparatus, a Water Tank, that uses PLIF, was used to study the seasonal summer wind in three-dimensions. For this simulation, a smaller portion of the Main Street District in Dallas, Texas was studied. As it is demonstrated in the pilot studies, architectural "Lego" was found to be the most appropriate modeling material for this experiment. The model was created in "Lego" 1"=100' scale. Also for the Water Tank simulation, another set of studies were conducted using only one building made of "Lego" scale 1"=100'. For each set of experiments each model was tested with and without green walls and roofs. The seasonal summer wind was tested coming from south.

4.4.1 Shallow Water Table

The Shallow Water Table simulation was conducted in order to obtain seasonal wind flow information on a pedestrian level. The model used for this simulation was a modeling clay model scale 1”=120’. It was the biggest model used and included the larger area of the Main Street District in Dallas, Texas. For this study, a series of videos were taken, above the model, to record the wind movement. Then, a series of pictures were taken using the video recordings. The results are as follow:

The first simulation conducted was of the model with only the buildings (see figure 4.20). The study showed that the summer seasonal wind coming from the south was not strong. The urban morphology did not let the simulated wind flow through the buildings and instead the simulated wind got trapped between the streets. Some vortices are formed especially in the streets where the density of the buildings and the building spaces are smaller. In the Main Street Garden, that was left without any infrastructure, barely any wind was received , and when it was it revolved around in vortices and then disappeared.

Figure 4.20 Shallow Water Table - Only Buildings (Big Portion District Model)

The second simulation conducted used the same model but added the existing and proposed green walls and roofs (see figure 4.21). The test showed that when green walls and roofs were added a change could be seen but the effect of green walls and roofs was not visually evident on a pedestrian level because of the scale of the model. Green roofs in this test did not contribute or affect the simulation in any form since the test allowed for only a couple of inches of water and did not reach most of the green roofs in the model. On the other hand the green walls affected the simulated environment creating vortices close to the building surfaces that had green walls. For example, in the area designated as where the Main Street Garden is, the flow of the wind was more visible than in the previous test without green walls and roofs.

Figure 4.21 Shallow Water Table - Buildings with Green Walls and Roofs (Big Portion District Model)

When comparing the two simulations (see figure 4.22), the test shows that in either situation the summer seasonal wind is not strong enough to let the air flow through the area. It is also evident that there is a change in the scenario when green walls are added but not green roofs because of the scope of the apparatus. In either case, the wind gets trapped between the streets and buildings indicating that the air does not flow because of the urban morphology. By adding green walls, the wind (vegetable dye) moves more in places depending on the building and its surroundings, but the benefit or disadvantage of green walls and roofs is not evident when doing this test.

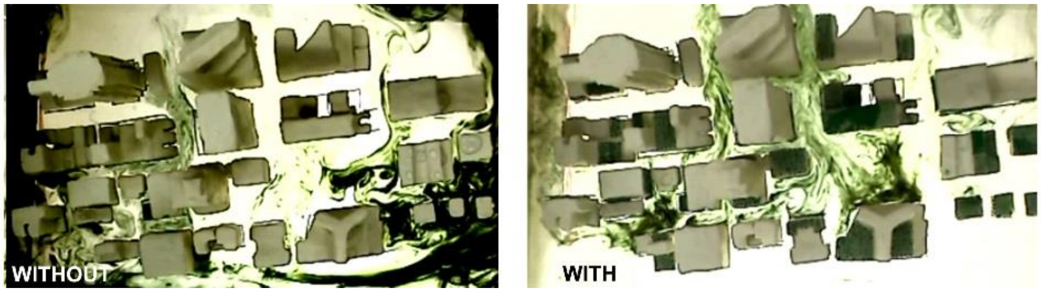


Figure 4.22 Shallow Water Table Comparison (Big Portion District Model)

4.4.2 Water Tank

The Water Tank uses a planar laser induced fluorescence (PLIF). These simulations were conducted to study the seasonal summer wind in three-dimensions. For this simulation, a smaller portion of the Main Street District in Dallas, Texas was studied. The material used for this model was “Lego” and the scale 1”=100’. Another set of simulations studies were conducted but using one building with the same material and scale.

1. The first sets of simulations with PLIF were conducted on a portion of the Main Street District (see figure 4.23). Starting with the model without green walls and roofs, the simulated wind gets trapped between the buildings and the flow creates vortices that wiggle around between the spaces. The area between the buildings simulates the Main Street Garden and, in this case, the simulated wind does not flow inside the area. There is a lot of energy between the buildings because the wind cannot flow. The fluorescing moves from east to west after revolving around.

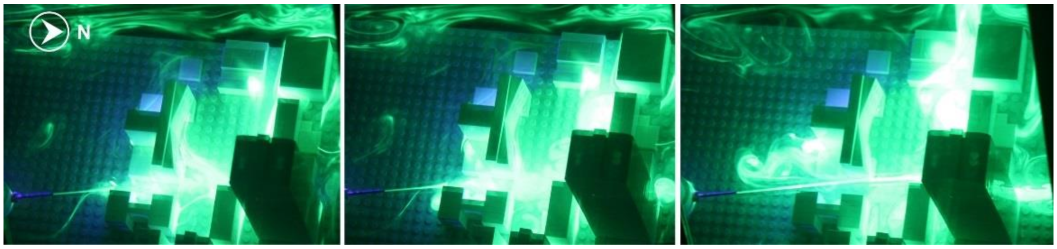


Figure 4.23 PLIF "Lego" Simulation (Smallest Portion District Model)

After adding green walls and roofs to the modeled area (see figure 4.24), the wind still gets trapped between the buildings but a vortex is seen at the Main Street Garden, like the wind moving inside of this area. There is a lot of energy in the east side and it slowly moves to the west side. It appears that the green walls help the wind flow better.

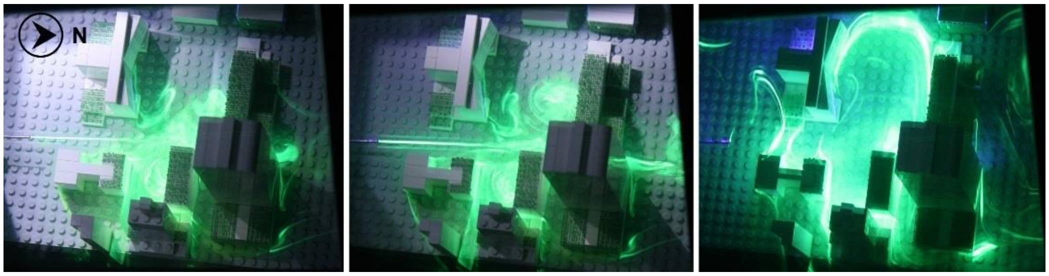


Figure 4.24 PLIF "Lego" Simulation with Green Walls and Roofs (Smallest Portion District Model)

When comparing the simulations of the “Lego” model with only the buildings, and then adding green walls and roofs (see figure 4.25), the test shows that the summer seasonal wind is not strong enough to let the air flow through the buildings. In either case, the wind gets trapped between the streets and buildings, especially when the building density is concentrated in an area. When green walls and roofs are added a change in the energy and wind flow is evident, even though the simulated wind still gets trapped, it moves more freely. In the test conducted with only the buildings, the wind does not flow into the Main Street garden area. In the test conducted with green walls and roofs, the wind does enter the area creating vortices and letting the wind spread out more.

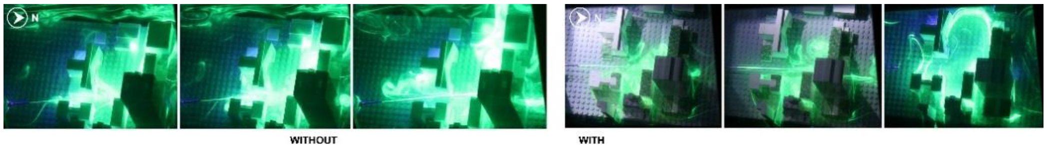


Figure 4.25 PLIF Comparison of Model with and without Green Walls and Roofs (Smallest Portion District Model)

2. The second sets of simulations with PLIF were conducted on one single building (see figure 4.26). First, a building without any addition was studied. When the simulated wind hit the building (fluorescing) the wind and energy move horizontally but just a few inches, creating vortices that revolved back to the building surface.

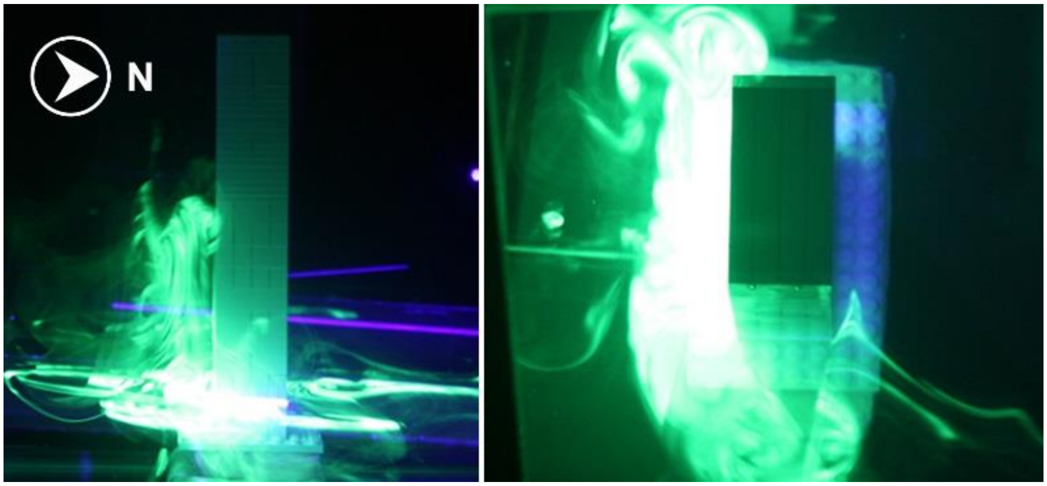


Figure 4.26 PLIF – Building

Secondly, a green roof was added (see figure 4.27), the same previous effect was seen but when the wind started flowing up, it looked like the green roof made the wind flow over. It was not possible to see a real effect.

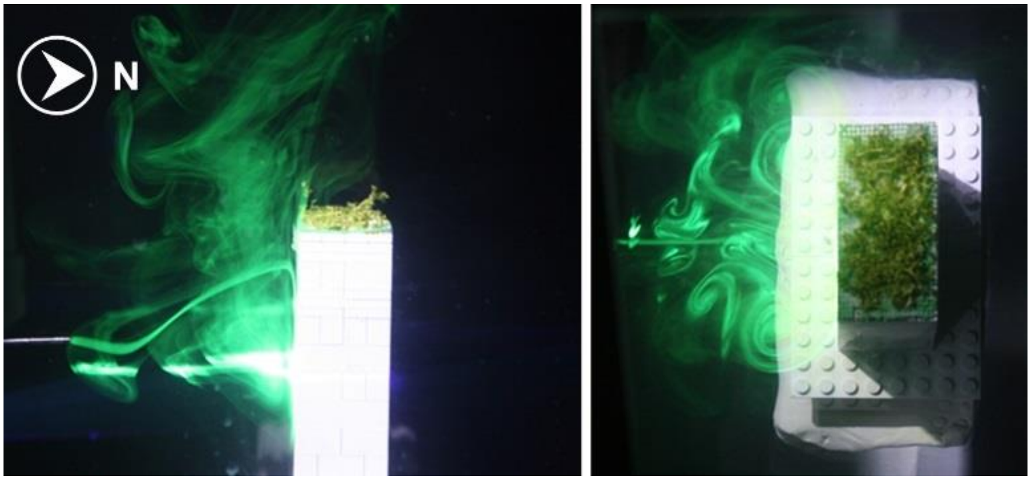


Figure 4.27 Building with Green Roof

When comparing the building model by itself and then with a green roof (see figure 4.28), the test gives limited results. When the wind hits the building nothing can be perceived regarding the green roof in that height. The only noticeable effect when the green roof is added is when the wind starts flowing up, it looks like the green roof helps it flow but it is not an evident result.

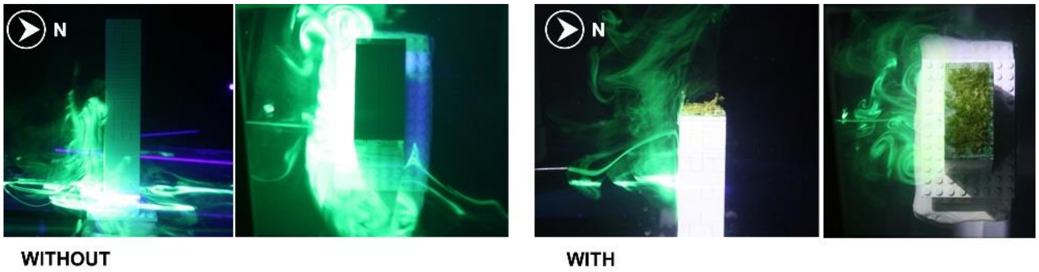


Figure 4.28 Comparison of Building with and without Green Roof

Thirdly, a green wall is added to the building façade as a second skin layer with distance between them (see figure 4.29). When the wind hits the green wall, part of the wind goes in the space between the green wall and the building façade and other part of the wind bounces over the green wall. There is a concentration of energy and wind in the stagnant air layer. Even though there are vortices, the wind does not stay on the surface of the green wall, and it moves out.

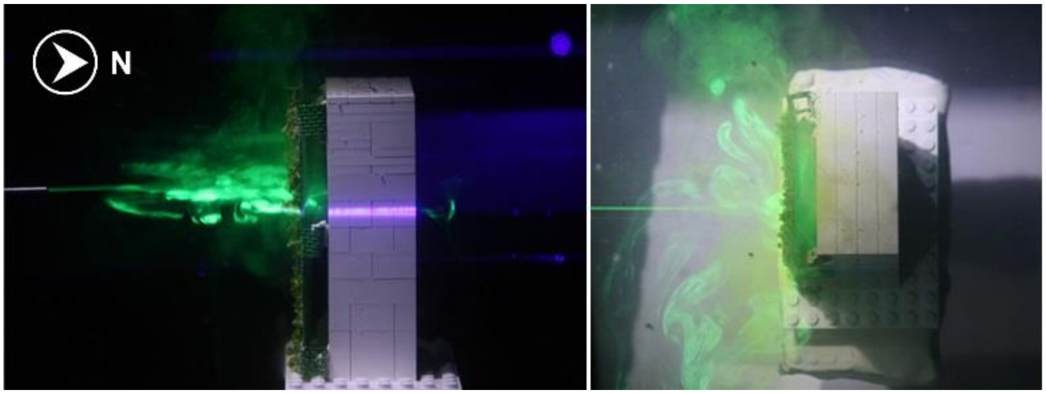


Figure 4.29 Building with Green Wall as a Second Skin

When comparing the building by itself and with a green wall used as a second skin wall (see figure 4.30), the test shows that by adding a green wall to the building the wind does not hit the building surface with such a strong energy and speed as without it. It is evident that the green façade makes a difference. When it hits the green wall, it looks like part of the wind gets absorbed, another part bounces out of the green wall surface, and another gets trapped between the green façade and the building wall.

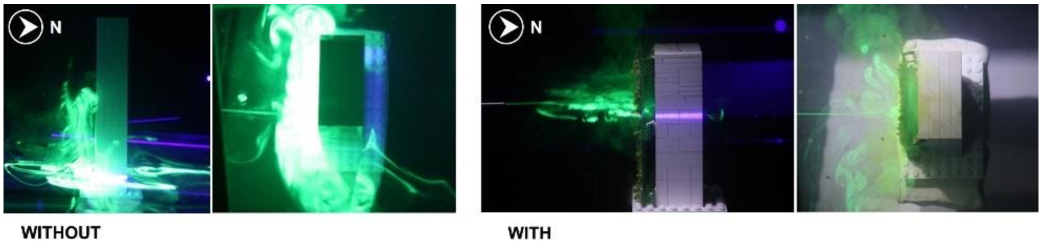


Figure 4.30 Comparison of Building with and without Green Wall as second Skin Layer

Four, a green wall is added to the building façade with minimum distance (see figure 4.31). The wind bounces back when it hits the green wall and then it moves vertically and horizontally away from the building. A vortex in each side of the building is formed moving away.

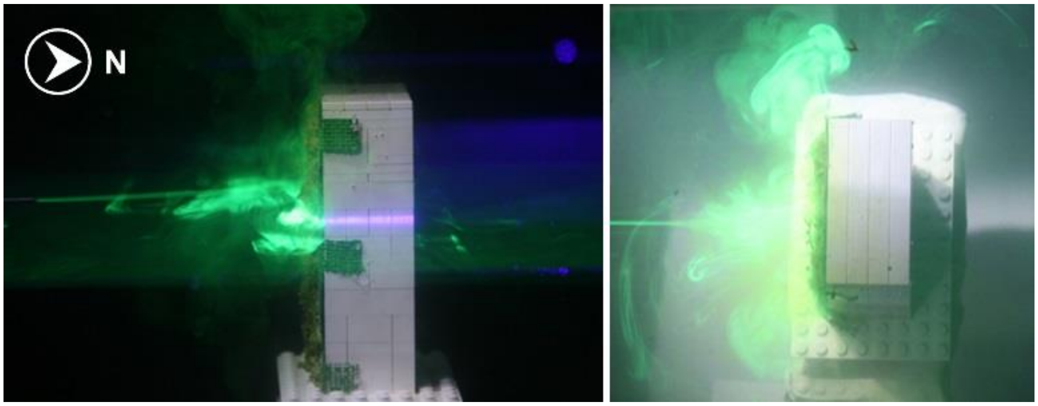
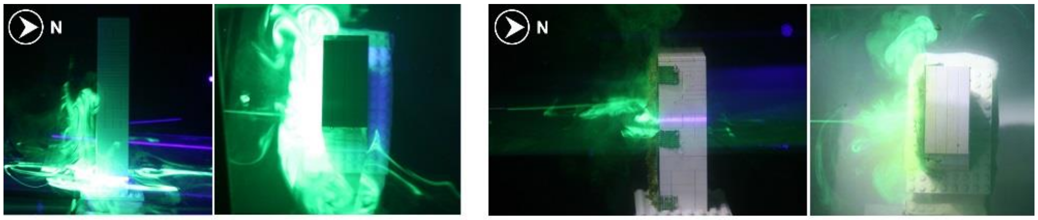


Figure 4.31 Building with Green Wall Attached to the Building Façade

When comparing the building by itself and then with a green wall attached to the building façade (see figure 4.32), the test shows that, by adding a green wall the wind that hits the building bounces back and out of the green wall, helping the wind move out and around the building surface. This result is evident that adding a green wall makes a difference because the wind actually flows and part of it is absorb by the green wall.



WITHOUT **WITH**

Figure 4.32 Comparison of Building with and without Green Wall

Fifth, a green wall and a green roof are added to the building (see figure 4.33). The wind hits the green wall and bounces back, then, it flows up reaching the side of the green roof. The wind moves vertically and horizontally away from the building surface, moving up and to the sides. The vortices formed are not clear.

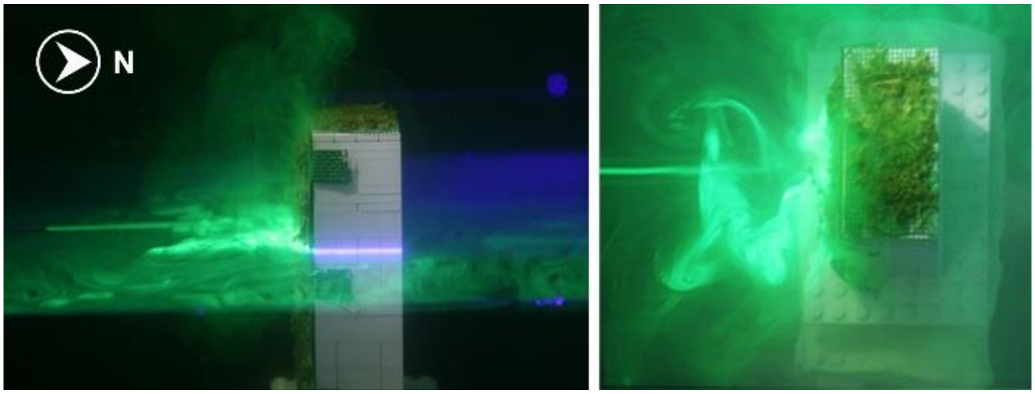


Figure 4.33 Building with Green Wall and Roof

When comparing the building by itself and with a green wall and roof added (see figure 4.34), the test shows that the wind flows better and the energy does not get concentrated onto the building surface. It is evident that by adding a green wall and roof part of the wind gets absorb by the surface and the grand majority bounces out of the building surfaces smoothly.

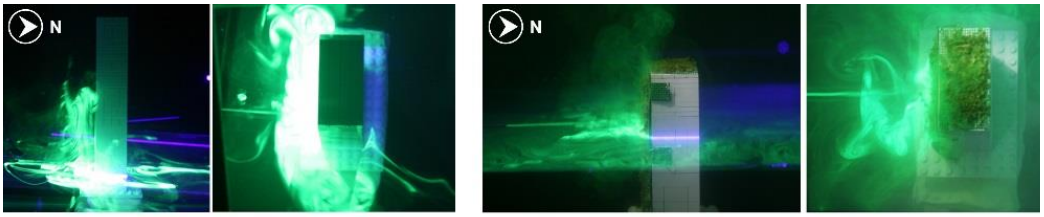


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Figure 4.34 Comparison of Building with and without Green Wall and Roof

According to the literature (Perez et al, 2011; Alexandri and Jones, 2006; Perini et al, 2013; Mazzali et al, 2013), a green wall system acts as a wind barrier and as a consequence, it blocks the effect of the winds on the façades of the building. The effect depends on a series of specifications: the density and permeability of the vegetation, the orientation of the wall and the direction, and velocity of the wind itself. All these measurements help increase the energy efficiency of the building just by blocking the wind. The blocking of the wind is important in the winter and in the summer. By placing green walls and roofs, the wind gets blocked and the demands of the cooling and heating systems of the buildings are reduced since the green walls and roofs wrap parts of the buildings surfaces. It is important not to obstruct the ventilation in the summer and not to help in the circulation of air in the winter. Wind decreases the energy efficiency of a building by fifty percent according to Ottele et al. (2011), but by applying a plant layer the green façade acts as a buffer and prevents the wind from moving alongside the building surface.

In one building simulation, two types of green walls were tested: one attached to the building surface, and the other one with the green wall detach and connected as a second skin layer. According to the literature, the space between the building and the green façade creates a stagnant air layer developing an insulation effect (Ottele et al., 2011). This was visualized in the simulation. The insulation capacity of living walls can depend on the substrate thickness. When a concrete wall is covered with vegetation the heat transfer is lower than with a concrete wall that is not covered; a living wall can reduce the energy that is transferred to the building by 0.24 kW h/m2 (Hoyano, 1988).

4.5 Summary of Findings

The urban heat island effects are caused by the way cities are built, the materials that are used, and the surfaces implemented within the cities. Dallas's climate is categorized as humid subtropical, with eight months of the year having a temperature above sixty eight degrees Fahrenheit and dry winters. The urban summer nighttime temperature of Dallas, Texas is almost four degrees Fahrenheit warmer than rural temperatures (EPA, 2009). During the daytime, the cooler surface areas are the ones covered with vegetation. Summer wind and sun patterns help the researcher visualize the influence they have in an urban environment such as downtown Dallas, Texas, with and without the implementation of green walls and roofs.

Green walls and roofs help lower temperature in urban canyons (Alexandri and Jones, 2006), and reduce the temperature inside and outside buildings (Susorova el al., 2013). Green walls act as wind barriers when attached to building facades or when used as a second skin layer. The implementation of these types of green infrastructure elements (green walls and green roofs) can help reduce sun exposure and act as wind barriers, and as a consequence help reduce the urban heat island effect.

The study revealed that there is still much to learn about the effects of green walls and roofs in the urban microclimate and future studies are encourage. The following chapter sums up the analysis and findings of this document, and suggests future research studies in the area of green walls and roofs, as well as their relationship with urban heat island effect.

Chapter 5

Conclusions

This research was conducted to evaluate the impact of green walls and roofs in the urban microclimate relative to helping alleviate the urban heat island effects in Dallas, Texas. Through simulated environments, two major constructs, wind and sun factors, are studied and tested for their impact. The empirical data obtained from the simulated environments were then compared with the pertinent literature. The strategy used in the research included: explore, forecast, testing, and learning (Deming and Swaffield, 2011). This research examined the validity of empirical data and the simulations. Simulated environments were a good visualization tool and helped the researcher to be hands-on with the data obtain from them. Doing simulations required practice and an understanding of experimental processes.

The research was set to answer the following questions: (1) Can green walls and roofs influence the solar exposure of buildings and districts to alleviate urban heat island effects in downtown Dallas? (2) Can green walls and roofs wall influence the seasonal wind patterns to alleviate urban heat island effects in downtown Dallas? (3) Can green walls and roofs help reduce the urban heat island effects in an urban dense area such as downtown Dallas?

5.1 Research Summary

The purpose of this research was to study the impact of green walls and roofs in the urban microclimate and their effects in alleviating the urban heat island effects. This research fulfilled testing certain aspects about the effects of green walls and roofs and the urban microclimate. The results obtained from the simulated environments helped the researcher obtain information about the relationship between wind and sun with the urban heat island effects, and how, when placing green walls and roofs, wind can flow better and the effects of solar radiation can be mitigated.

Testing and experimenting in simulated environments can be informative and effective when studying natural environments on a greater scale. They can allow greater control over confounding variables that may be influential in full scale/on-site experiments, provide environment for replication within the confines of the experiment, and most importantly may control the time factor. Simulated environments create an opportunity for the researcher to visualize everything from the process to the results and allow for variables in the simulation to be changed and moved. Simulated environmental models were used to represent a portion of downtown Dallas, Texas, and allowed the study to change different variables in the wind and sun studies, such as the addition of green walls and roofs.

According to the National Weather Service, Dallas, Texas has an average high winter temperature of sixty-one degrees Fahrenheit and, an average high summer temperature of ninety-six degrees Fahrenheit (NOAA, 2012). Studies indicate that the urban heat island effects can increase the temperature six to eight degrees Fahrenheit (HARC and EPA, 2009) and create a warmer microclimate in the downtown area. The Leadership in Energy and Environmental Design (LEED) encourages the use of green walls and roof systems to reduce microclimates created by infrastructures and buildings (USBG, 2013).

When studying the impact of man-made structures in the natural environment using simulated environmental models, it is important to define the variables to be studied. In this research two sets of studies were conducted for seasonal wind patterns and for sun exposure. First, a set of simulations were made using two models with only buildings in them. The second set of simulations were made using the same models but adding green walls and roofs to the buildings.

Simulated environmental models served as the tool for data collection for the use of green walls and roofs in an urban microclimate. In this case downtown Dallas, Texas, was used as the area of study. The influences that these type of green infrastructures have in reducing the urban heat island effect by alleviating the solar exposure and wind was determined.

In summary, adding green walls and roofs onto a building and urban models in simulated environments suggests potential impact. The results of the simulations suggest that, sun exposure is lessened and seasonal summer wind flow is diverted and/or dispersed in all of the simulations.

5.1.1 The Influence of Solar Exposure to Urban Heat Island Effects

Summer sun exposure is intense since the days are longer and the sunlight can be seen before six am and after eight pm in downtown Dallas, Texas. When green walls and roofs are added, the sun exposure is not directly on the building surfaces but instead is collected by the green walls and roofs, provoking a change in the indoor and outdoor temperature according to the reviewed literature (Perini et al., 2011; Mazzali et al., 2013Susurova el at., 2013). In the sun studies, the simulation is limited to the shadow pattern and sun exposure. The effects in energy consumption are not able to be visualized or measured when using this type of simulation.

5.1.2 The Influence of Seasonal Wind Patterns on Urban Heat Island Effects

Summer seasonal winds come from the south in Dallas, Texas. Both of the simulations, PLIF and Shallow Water Table, were tested according to the summer seasonal wind pattern. When doing the simulations without green walls and roofs, the wind appeared to get trapped between narrow streets with a higher building density.

When adding green walls and roofs, the wind still got trapped but the wind appeared to flow with more ease. According to the literature, since the wind comes from the south in summer months, the warm temperatures flow towards the northwest (Winguth and Kelp, 2013). The blocking of the wind when using green walls acts as a barrier to the effect of the wind on the building envelope, increasing the efficiency of the building (Susurova et al., 2013).

5.1.3 Reducing the Urban Heat Island Effects when using Green Walls and Roofs

Adding green walls and roofs onto a building and urban models in simulated environments suggests potential impact. The results of the simulations suggest that sun exposure is lessened and seasonal summer wind flow is diverted and/or dispersed in all of the simulations. When the simulations are conducted, the influence of green walls and roofs are visible but the study is limited to the wind pattern and, the effects and the efficiency of the building is not visualized with simulations.

5.2 Conclusions and Discussion

Green walls and roofs are landscape features attached to architecture that forms part of an urban environment. The urban microclimate of the cities changes as more buildings and infrastructures are built. It is important to consider options to mitigate the urban heat island effects caused by the urban microclimate and to study how wind and sun play a role into this discussion. “According to Akbari and Taha (1992), in general, climatic factors that affect outdoor thermal comfort are (1) surface and air temperature; (2) relative humidity; (3) solar radiation; and (4) wind velocity… climatic elements and its relation with local climate should be fully understood” (Thani et al., 2012, p. 441). The literature illustrates that by adding vegetation into the urban environment, the urban heat island effects can be mitigated(Kleerekoper et al., 2012), and two of the applications of vegetation are studied and tested here were green walls and green roofs.

By doing simulation environments tests and experiments, wind and sun can be studied in different scenarios and changing and moving variables. Confounding factors can be controlled, and cost and time spent in understanding the phenomena can be reduced. A simulated environment gives the researcher hand-on empirical data and access to the process of gathering data. It is important to recognize that there are computer programs that allow the user to recreate urban environments and to obtain information about wind patterns and sun exposure, but the information provided with such digital tools, are products of a click of a button and the process is not available.

Dallas' climate is categorized as humid subtropical, with eight months of the year having a temperature above sixty eight degrees Fahrenheit with dry winters. The city receives most of its precipitation in the spring with some heavy-rains occurring in the summer for brief periods of time (Winguth and Kelp, 2013). Dallas is facing critical challenges because of the high temperatures including rising energy costs, air quality, and health. Because of the higher temperatures, the demand for electricity for air conditioning rises especially in the summer time. For Dallas, the cost of additional electricity caused by the urban heat island effects likely amounts to several hundred million dollars per year when compared to other cities. "Widespread heat island mitigation measures, such as cool roofs and extensive tree planting, could produce energy savings of forty to fifty million dollars annually. These savings would be offset somewhat by the costs of implementing these measures, but the net benefit would be substantial" (HARC and EPA, 2009, p. 5). By adding green walls and roofs, the urban heat island effect in downtown Dallas as well as in North Texas can be mitigated to a certain degree.

5.3 Relevance to Landscape Architecture

Landscape architecture is a profession that combines arts and sciences to shape and influence architecture, landscape, and urban form. It is an academic field and an area of practice that is primarily concerned with the well-being of nature and ecology in relation to human and built environments. It is critical that landscape architecture has a greater understanding of the sciences to generate knowledge necessary to shape future built environment. For this reason, the study of green walls and roofs and the impact they can have in reducing the urban heat island effects is important for the landscape architecture scholar and profession. As it is illustrated in this research by doing simulated experiments, the empirical data can be obtained to highlight the importance and relevance of green infrastructure elements such as green roofs and walls in urban environment. Such evidence based knowledge can equip landscape architectural professionals with information that demonstrates social, economic, and environmental value of design practices (Ozdil, 2008).

This research also illustrates that the use of simulated environments as a mean to visualize and discover information in landscape architecture would be an effective way to gather and disseminate knowledge. The use of models, simulations, and/or quasi-experiments in landscape architecture research and education not only diversify the research tools available to landscape architecture scholars but also produce empirical results with greater efficiency.

5.4 Future Research

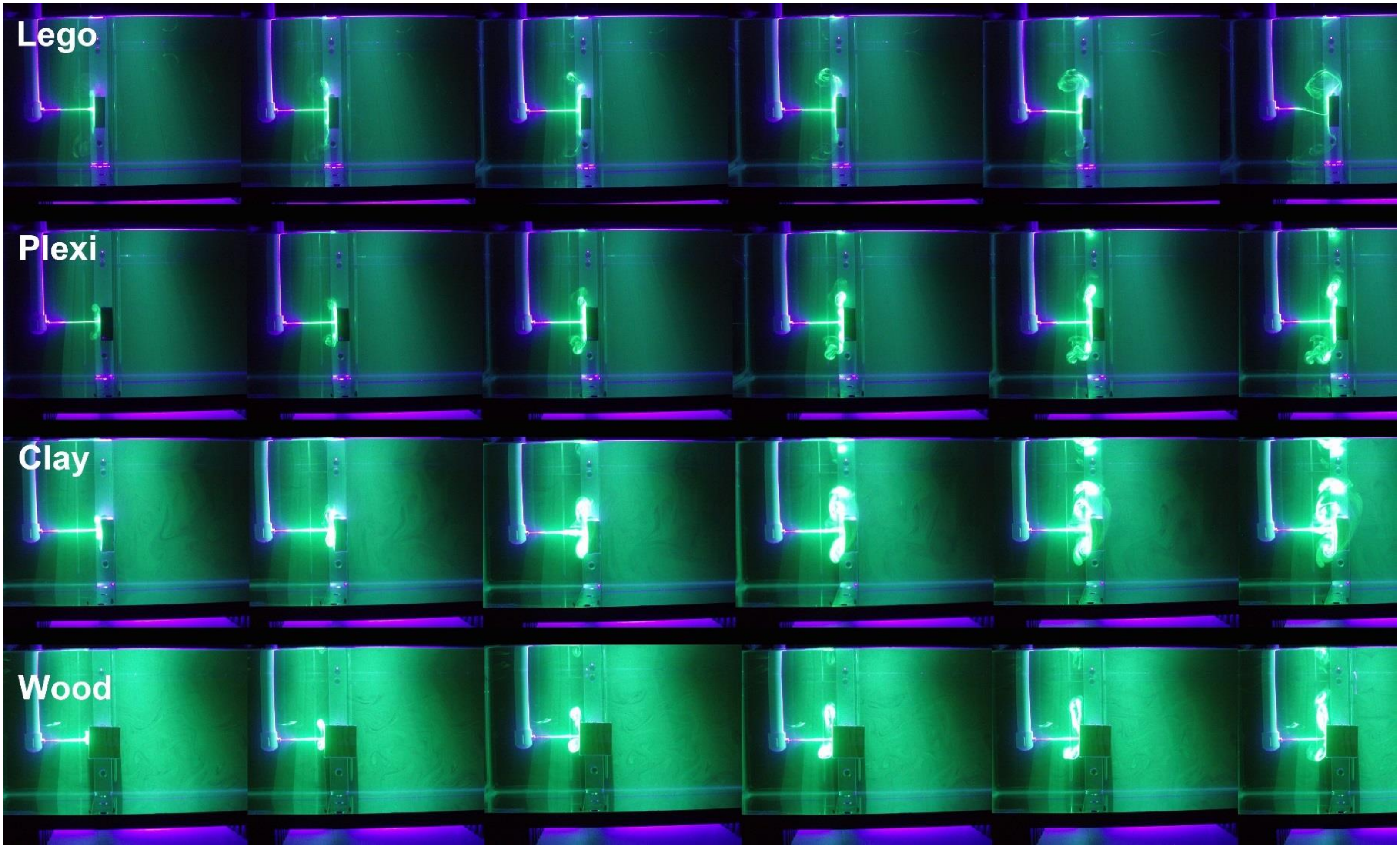
Although this research attempted to answer questions about the impact of green walls and roofs and their role in mitigating the urban heat island effects in downtown Dallas, Texas, it also developed other questions for future research. Those questions for future research include:

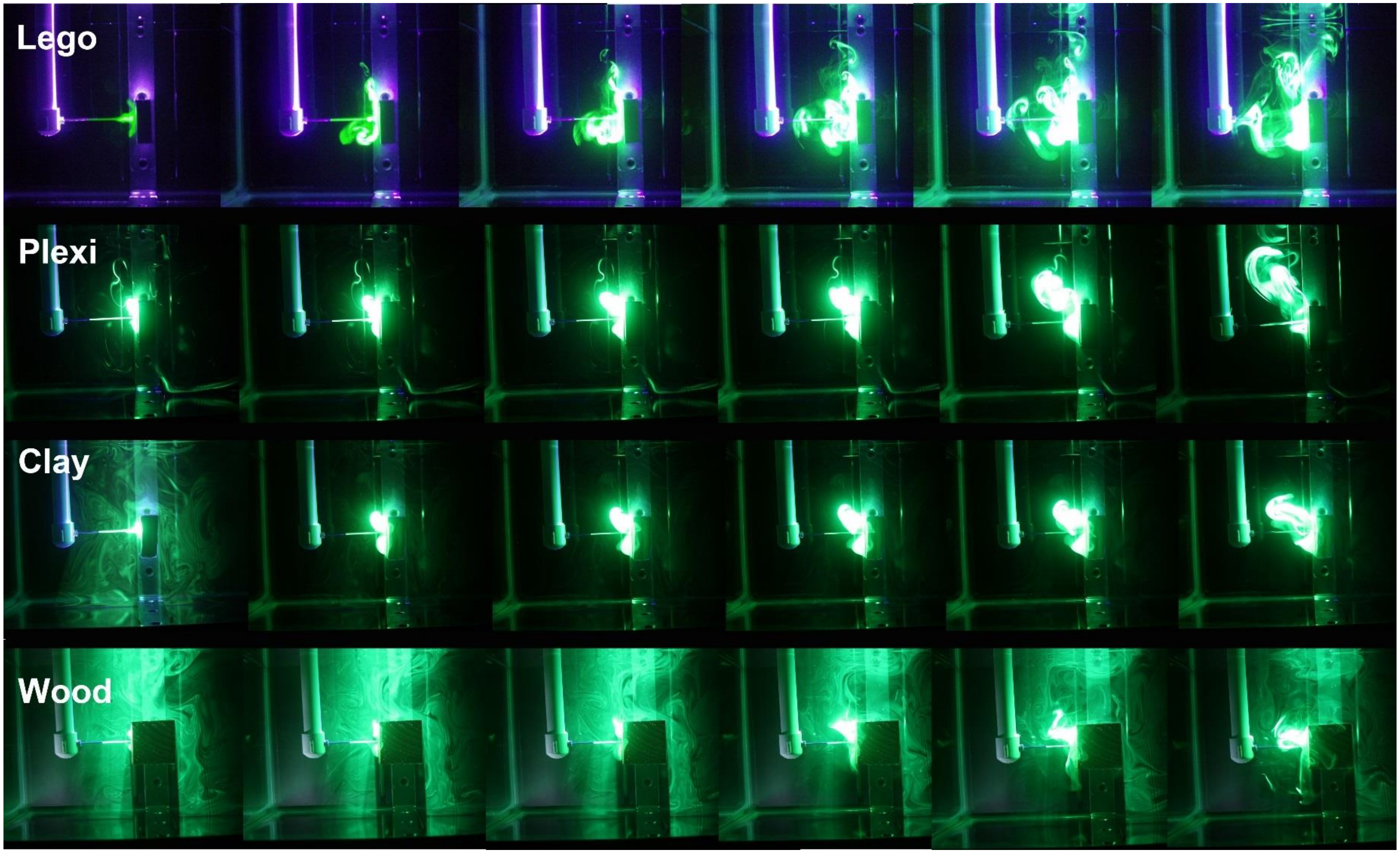
1. The impact of green walls and roofs can be studied in different categories and typologies such as intensive and extensive green walls and roofs.
2. Other green infrastructure components for mitigating the urban heat island effects through vegetation can be studied in downtown Dallas, Texas.
3. More simulated environments can be tested adjusting and testing different variables such as temperature and humidity in the same setting of downtown Dallas or other places around the world.
4. A comparison between cities with the same meteorological conditions but one with green walls and roofs and one without can be compared.
5. A study of different green walls typologies and the impact of wind can be studied.
6. Physical models and computer models of the same city can be made and compared for the same research questions set forth in this research as well as for other research questions.
7. A quantitative study using simulated experiments and extracting data with *Mat Lab* software package can be done to obtain and acquire statistical findings from such research.
8. Cost and benefit analysis for of green walls and roofs can be made for different built environments.
9. The beneficial effects of further design and configuration of urban environment with the proliferation of green walls and roofs can be examined.

Appendix A

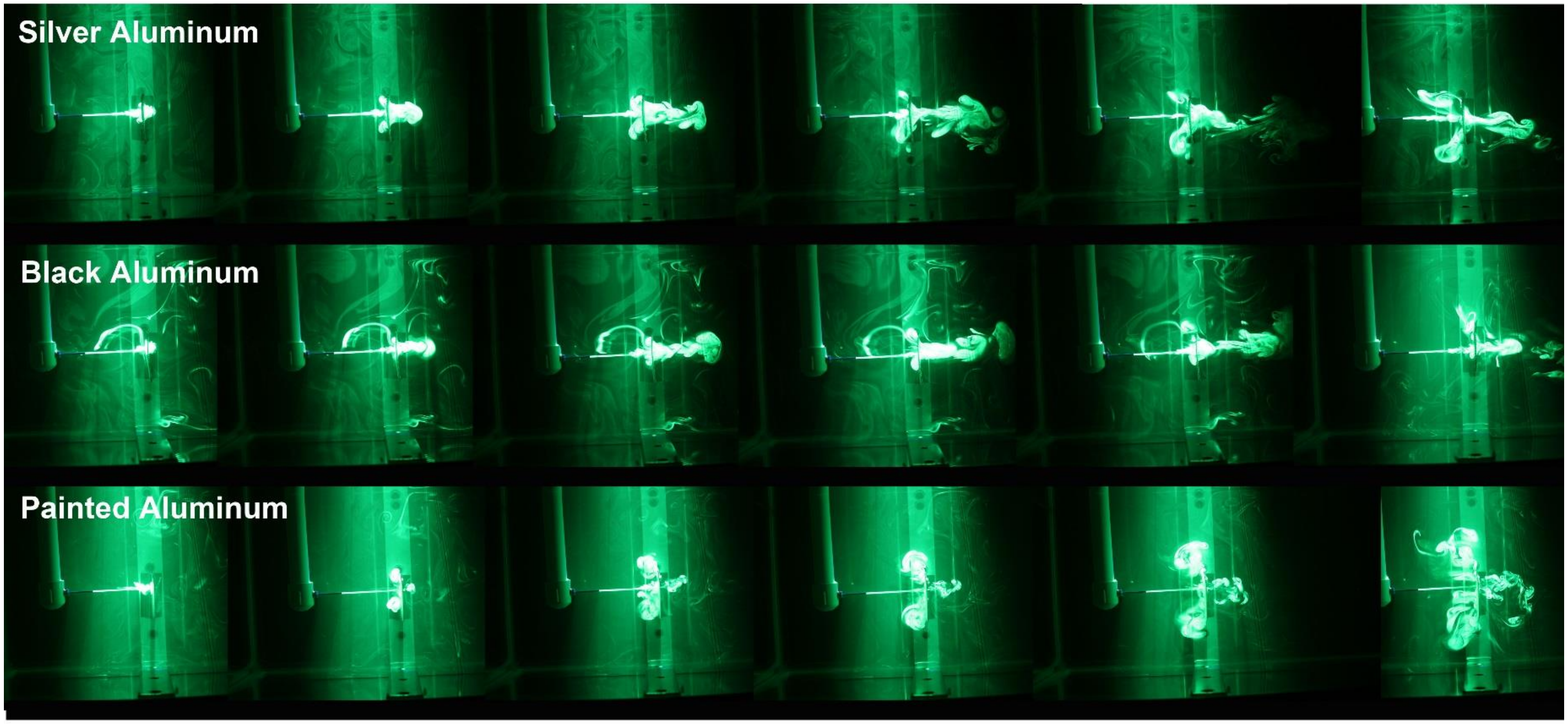
Testing the Materials and the Equipment

This appendix contains images of various equipment and material used in this research


Lego
Plexi
Clay
Wood


Lego
Plexi
Clay
Wood

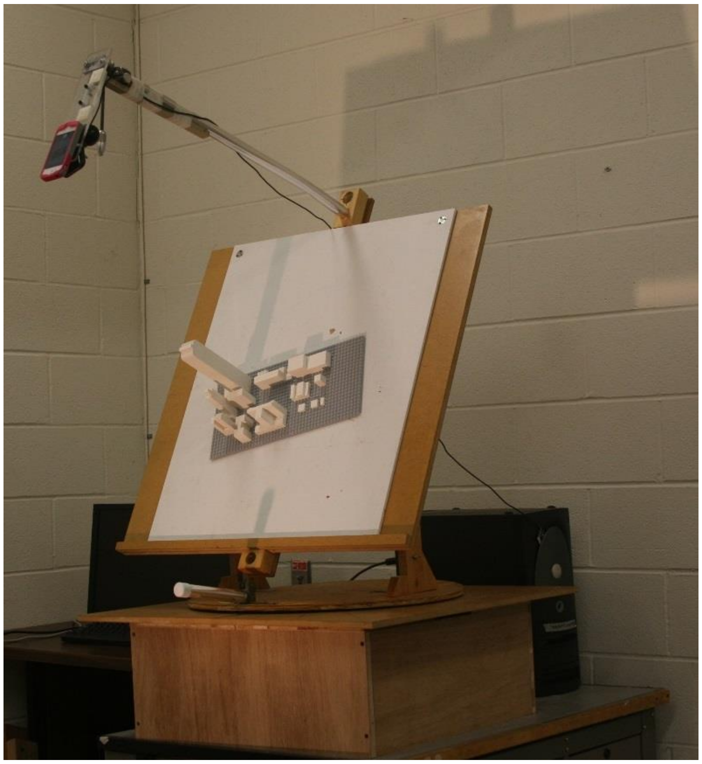
Pilot Study Screens - Sequence



Appendix B

Sun Studies

This appendix contains images of various equipment and material used in the sun studies



Appendix C

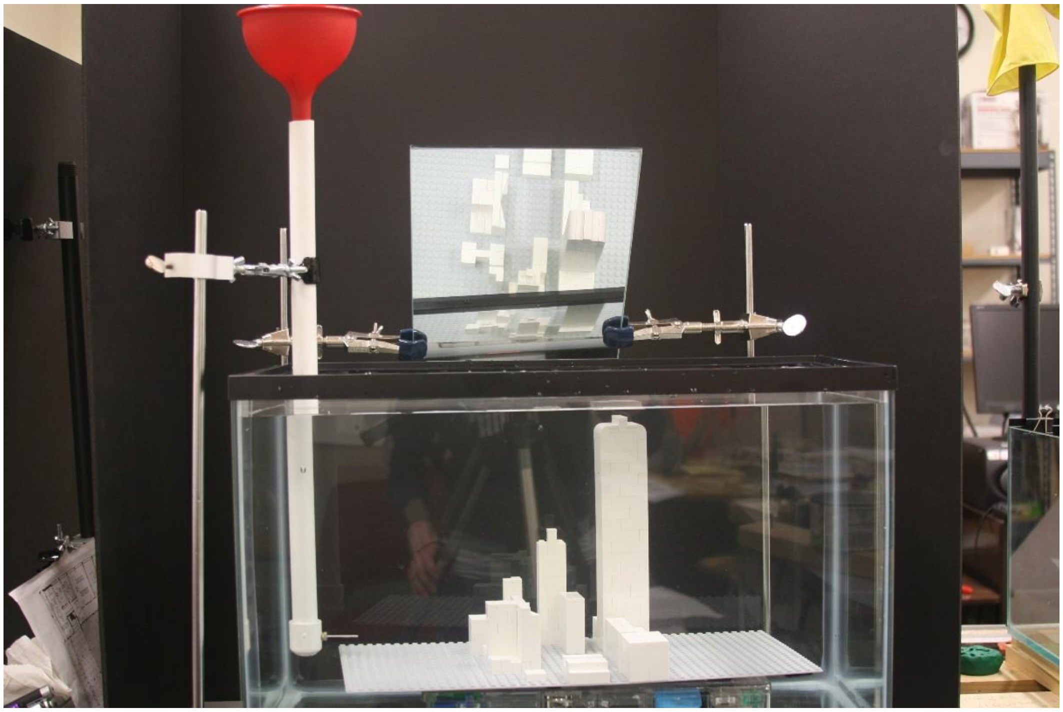
Wind Studies (Shallow Water Table)

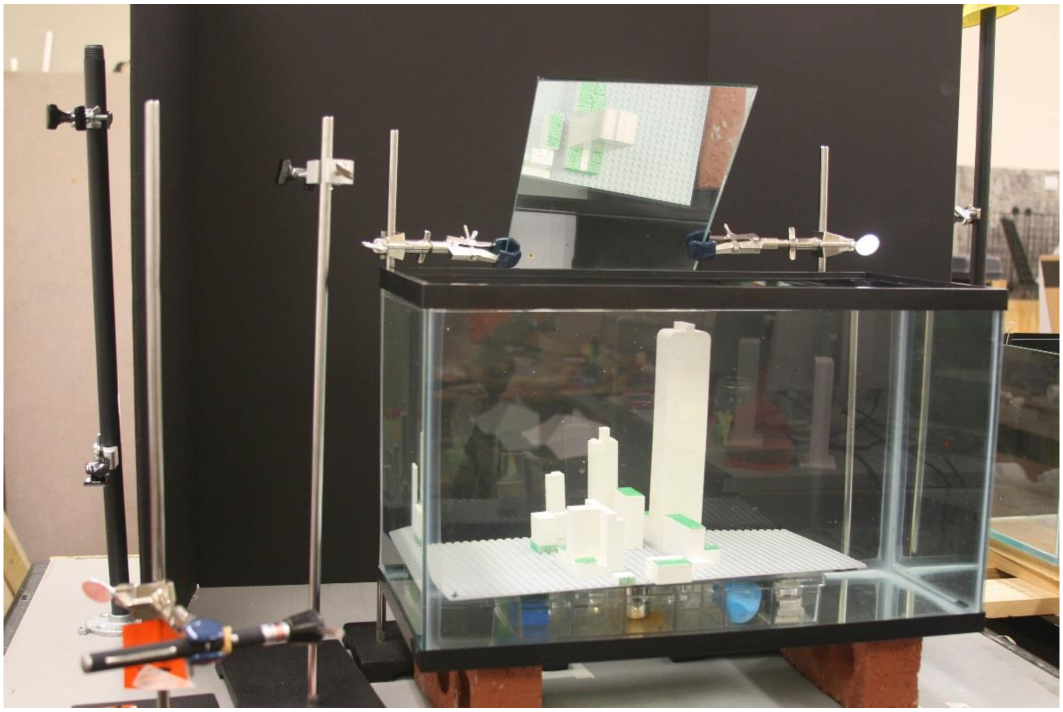
This appendix contains images of various equipment and material used in the wind studies

Appendix D

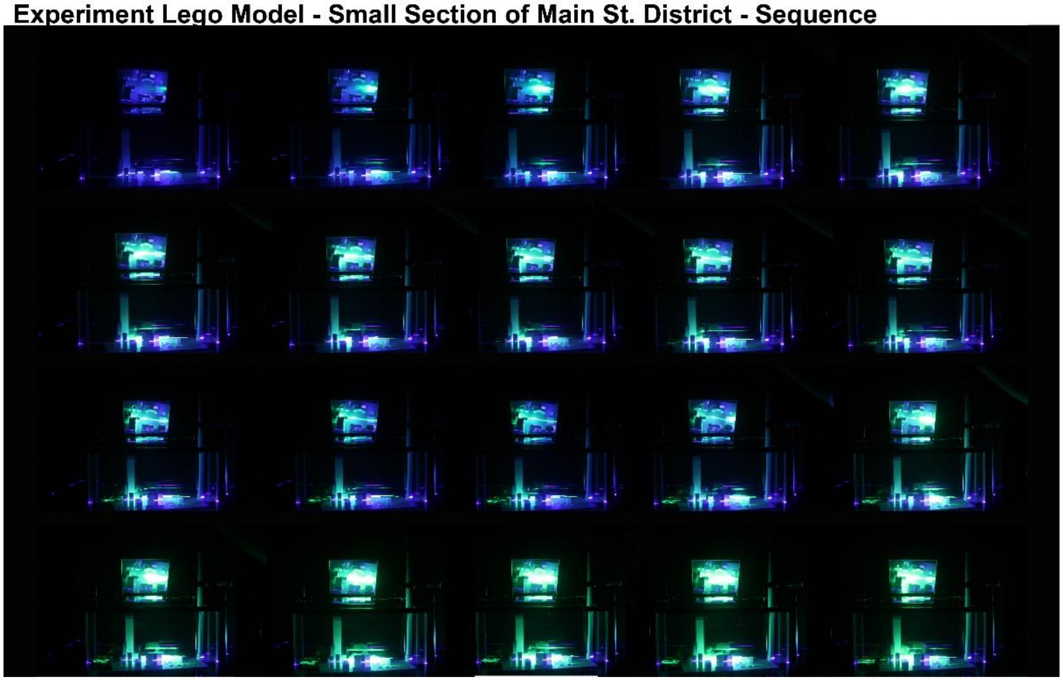
Wind Studies (PLIF)

This appendix contains images of various equipment and material used in the wind studies





Experiment Lego Model - Small Section of Main St. District - Sequence



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Biographical Information

Dalit Bielaz Sclar was born and raised in Monterrey, Mexico. She graduated from the Instituto Tecnologico y de Estudios Superiores de Monterrey with a bachelor's of Architecture. During her undergraduate studies she started learning about sustainability, global warming and landscape architecture and decide to pursue a masters in landscape architecture after finishing her bachelors. In her last semester of undergraduate degree she did an internship with Prohabitat were she was exposed to architecture, urbanism, and landscape and confirmed her desire of the masters. After graduation she kept working at Prohabitat until she got engaged and moved to United States with her fiancé.

It took her two years to start her master's degree at the University of Texas at Arlington. During her studies she did an internship during her first summer, worked as a graduate research assistant for Professor David Hopman for a year and is currently doing an internship at the Arlington Urban Design Center. She is interested in finding the balance between architecture and landscape architecture in a sustainable way, and how to help the planet become a better one.