1 INTRODUCTION

1.1 Background

Rapid urbanisation in cities has led to the substitution of natural habitats by artificial and harsh surfaces. This loss of green open space has reduced infiltration and evapotranspiration, and increased solar radiation absorption by city surfaces such as concrete and tarmac. This has led to the Urban Heat Island (UHI) effect, where higher average temperatures exist in densely populated and built urban areas compared to surrounding rural lands (Takakura *et al*, 2000). Rapid urbanisation leads to large increases in energy consumption to cool and heat buildings. This, intensified by the UHI, induces a corresponding increase in electricity generation leading to excessive resource consumption, air pollution, global warming and other environmental issues.

Installing green spaces in cities can serve multiple ecological-environmental functions. Since there is a shortage of open space in most cities, bare and unused rooftops can be used to enhance urban vegetation cover. These vegetated roofs called green roofs, living roofs or ecoroofs serve several purposes such as functioning as an insulation layer to lessen cooling and heating expenditures, cooling the ambient air, absorbing rainwater, improving the quality of rainfall runoff, reducing solar radiation absorption, creating habitats thus increasing biodiversity, aesthetic benefits and reduction of noise pollution (the soil helps block lower frequencies and the plants block higher frequencies) (Del Barrio, 1998; Laar and Grimme, 2006; Alexandri and Jones, 2007; Greenstone, 2009; Jim and Tsang, 2011).

There are two green roof types; namely intensive (Figure 1-1) and extensive (Figure 1-2) (van Wyk, 2009). Intensive green roofs use deep growing medium (more than 15cm) and extensive green roofs make use of shallow growing medium (less than 15cm). Intensive roofs place more loading on a roof structure and require more maintenance yet they facilitate the growing of a variety of plants such as trees and shrubs. Extensive roofs which are lighter and need less maintenance are most popular. Plants with shallow rooting systems are grown on extensive roofs (van Wyk, 2009).

Figure 1-1: Intensive green roof (Weeder, 2010).

Figure 1-2: Extensive green roof (Weeder, 2010).

There are two approaches to extensive green roof planting: modular (placing the growing medium in trays) and direct (laying the growing media on assorted protective layers) (Greenstone, 2009). These two methods of extensive green roof planting are illustrated in Figure 1-3 and Figure 1-4.

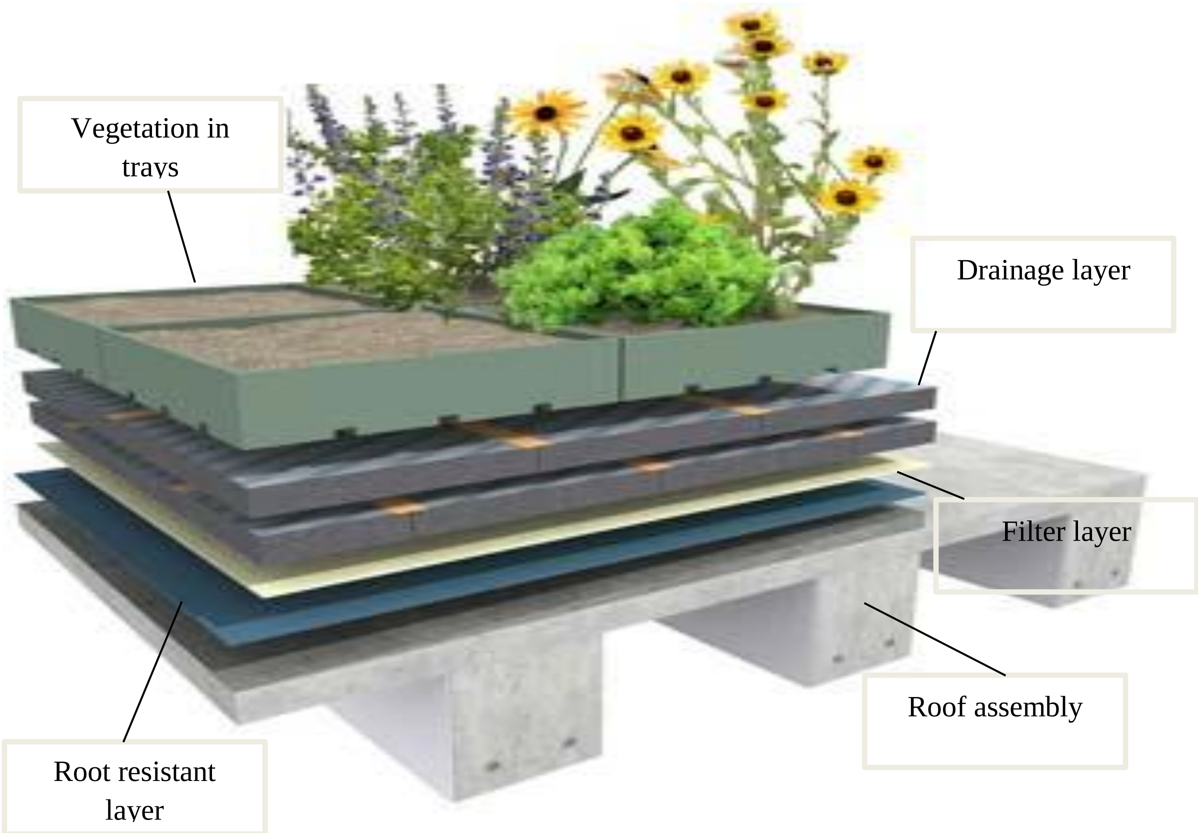

Figure 1-3: Modular green roof planting (Adapted from UK Urban Development Services, 2008).

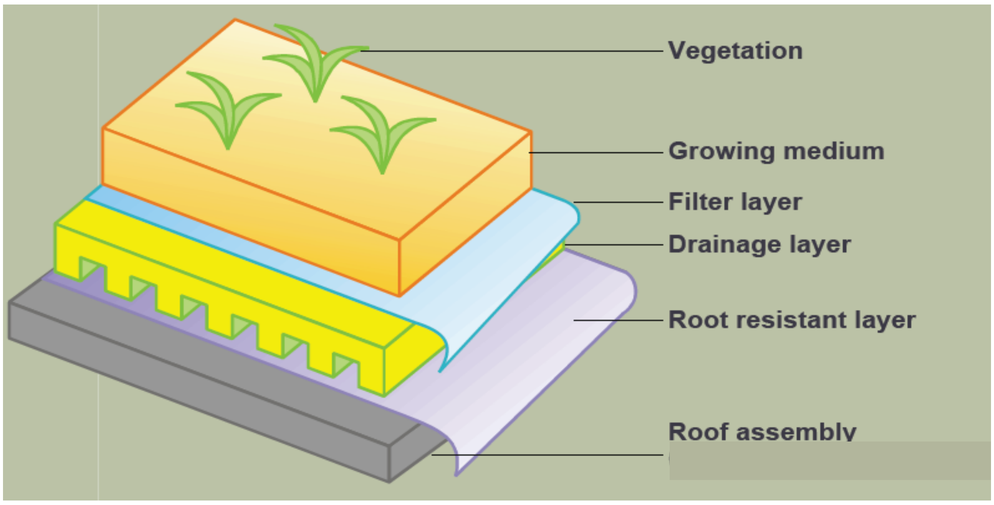

Figure 1-4: Components of a direct application extensive green roof. (Adapted from Liu, 2006).

This study focuses on the *thermal benefits* of green roofs, and makes use of *direct application extensive green roofs* to study the latter.

In general, thermal performance of green roofs is either defined as the ability of green roofs to reduce energy consumption for winter heating and summer cooling (Sailor *et al*, 2008; Castleton *et al*, 2010), or the ability of green roofs to mitigate the UHI effect (Alexandri and Jones, 2007). In this study, the ability of green roofs to lower the cooling energy demands of buildings is of interest.

Factors (Figure 1-5) identified as affecting the thermal performance of green roofs are evapotranspiration (Liu and Baskaran, 2005; Jim and Hongming He, 2010), shading (Liu and Baskaran, 2005), insulation (Del Bario, 1998; Liu and Baskaran, 2005) properties of the soil and foliage, and increased thermal mass (Liu and Baskaran, 2005). Green roofs regulate internal temperatures by regulating temperatures incident on roof surfaces, as well as decreasing heat transmission between the external environment and buildings by acting as an insulation layer. In summer, temperatures are reduced through shading and evapotranspiration. As water evaporates from leaves, heat energy is absorbed and heat flow through the roof is minimised. On the other hand, in winter, the growing media provides insulation therefore decreases heat loss. Nevertheless, green roofs have been observed to be effective in averting heat gain rather than heat loss (Del Barrio, 1998).

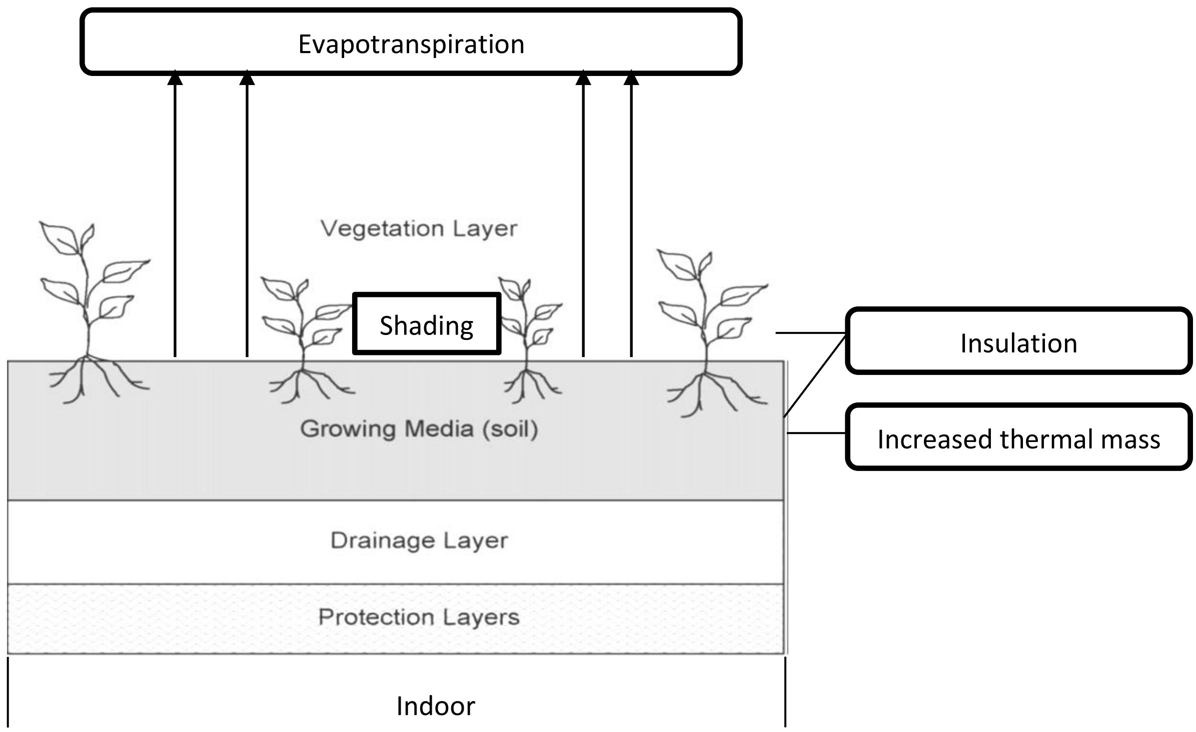

Figure 1-5: Factors affecting the thermal performance of green roofs (Adapted from Liu, 2006).

1.2 Problem statement

The establishment of green roofs locally and worldwide is on the rise. Parallel to this, green roofs are also emerging as a worthwhile field of scientific endeavour. Worldwide, studies on green roofs include, among others, thermal performance (Del Barrio,1998; Laar and Grimme, 2006; Alexandri and Jones, 2007; Jim and Tsang, 2011), storm water retention and quality (Villarreal and Bengtsson, 2004; Van Woert *et al*, 2005; Wachtel, 2007), habitat creation and urban biodiversity (Angold *et al*, 2006), life cycle analysis (Kosareo and Ries, 2007; Carter and Keeler, 2008), vegetation composition and structure (Dunnettt *et al*, 2005; Emilsson, 2008), substrate composition (Emilsson, 2008), and establishment method (Emilsson, 2008).

In South Africa, investigations are underway in Durban. The eThekwini green roof pilot project includes studies on the use of different plant species, surface runoff quantity and quality, and biodiversity. The pilot project was done to give an understanding of the city's susceptibility to climate change (Greenstone, 2009). In the Highveld, a study was done on the thermal benefits of green roofs in winter (Opeka and Martin, 2010).

Although it is well known that soil water content (SWC) strongly influences the thermal properties of soil (Sailor *et al*, 2008), few studies have focussed on the effects of SWC on the thermal performance of green roofs. SWC differs with climate, and may have repercussions in terms of the thermal benefits of green roofs in varying rainfall regions.

1.3 Objectives of this study

The aim of this study is to understand the effect of SWC on the thermal performance of green roofs; with the overall objective of determining the effectiveness of green roofs under various climatic conditions.

The specific research objectives are as follows:

- To determine how SWC affects the thermal performance of green roofs.
- To evaluate how SWC can be used to manipulate the thermal performance of green roofs.
- To distinguish guidelines to optimise the design of green roofs under various climatic conditions.

1.4 Report layout

This report is structured as follows:

Chapter 2 defines green roof thermal performance for the purpose of this study; and reviews the soil thermal properties that may affect it. The effect of SWC on the latter is elaborated upon, with the aim of understanding its role in regulating the thermal properties of green roofs. A summary of research questions concludes this chapter.

The methodology used to answer the research questions is explained in Chapter 3. The results and analysis are presented in Chapter 4; and conclusions and recommendations follow in Chapter 5.