Report of Findings

Team 8: Green Roofs

CCDP 2100 X

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6.0 REDUCING THE URBAN HEAT ISLAND EFFECT (Joshua Gatto)

Figure 6.1: Green city and regular city [1]

The purpose of Section 6.0 is to explain how evapotranspiration of the plants in the green roof can aid in reducing the urban heat island effect. In Section 6.1 of this report, the urban heat island effect is defined. Section 6.2 introduces the subtopic evapotranspiration. Finally, Section 6.3 presents the methods used by green roofs to mitigate the urban heat island effect.

6.1 The Urban Heat Island Effect

The urban heat island effect is the concentration and retention of heat in large cities. The urban heat island can be caused by building material heat retention and heat sources including the sun, people, cars and buses. It is estimated that heat islands can cause temperature differences of as much as 5 [1].

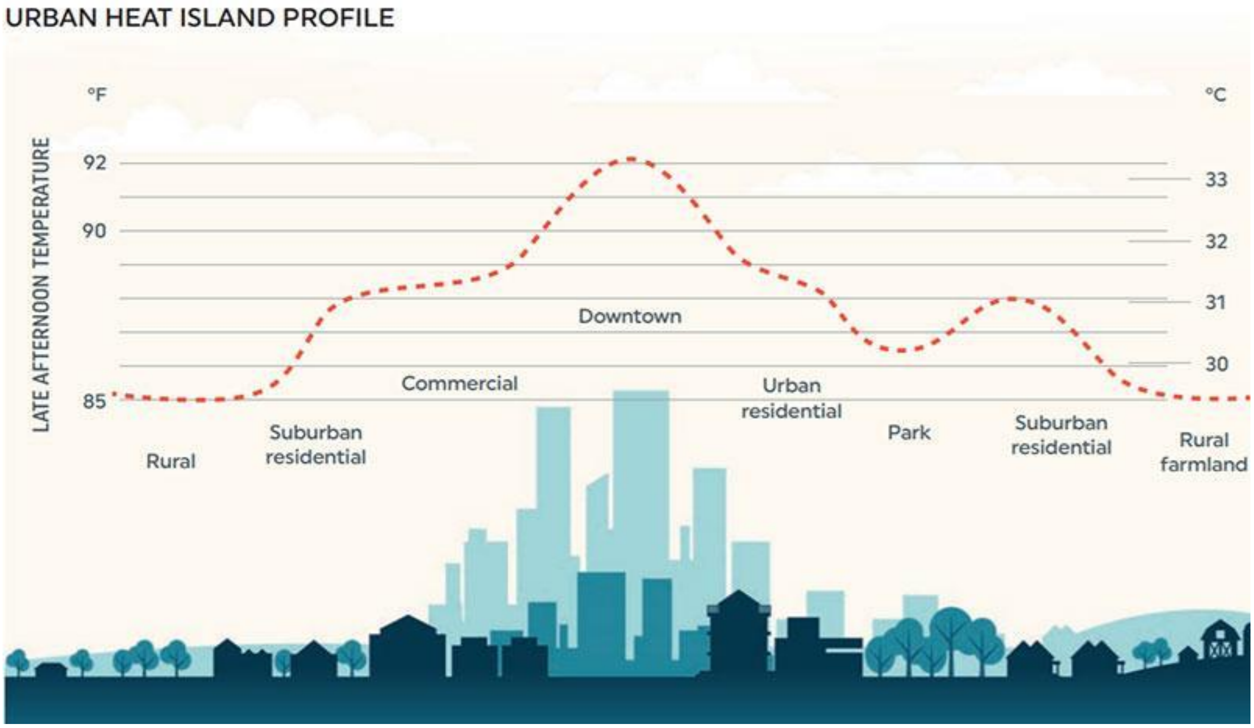

Figure 6.2: Heat difference over landscape change [2]

6.2 Evapotranspiration

Sections 6.2.1 and 6.2.2 describe the scientific theories behind evaporation and transpiration, respectively. Section 6.2.3 explores the thermal properties of water. Evapotranspiration is the combined process of evaporation and transpiration, both providing a cooling effect. To understand the cooling effect of evapotranspiration, evaporation must be studied first.

6.2.1 Evaporation

Evaporation can be explained using three principles from the particular theory of matter that apply to all matter. The first concept states that all particles are in motion [3]. The second states that when particles are heated, they increase in speed. Finally, all particles are attracted to each other through intermolecular forces called bonds. With these three concepts, the process of evaporation can be explained in three steps. First, particles in liquid state are at some ambient temperature, seen in Figure 6.2a. Once the particles are heated, they begin to increase in speed (Figure 6.2b). Eventually, the speed becomes so great that the bonds break, allowing the particle to jump off the surface of the liquid into the atmosphere (Figure 6.2c).

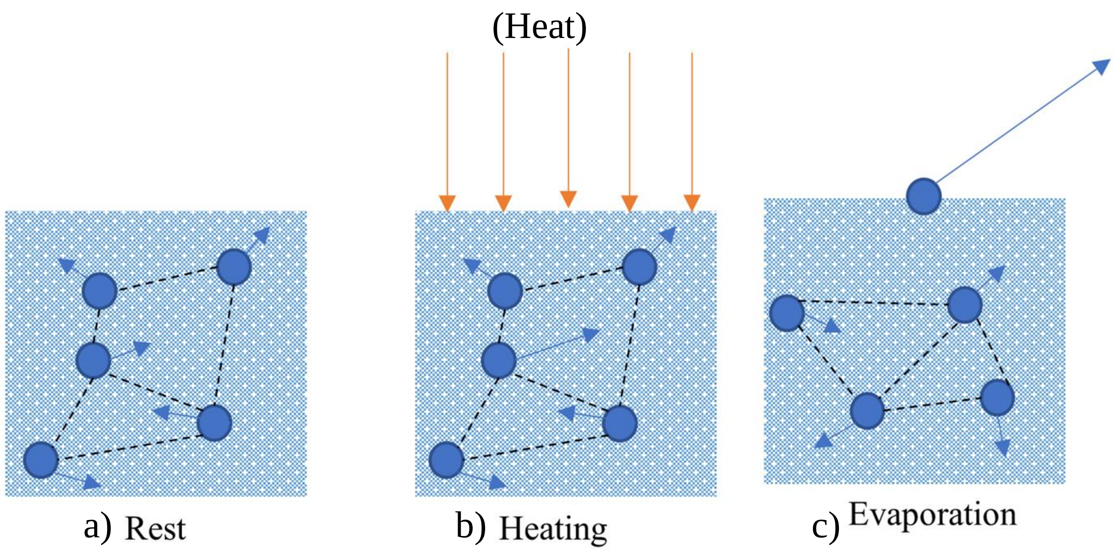

Figure 6.3: Evaporation process [Joshua Gatto]

6.2.2 Transpiration

Transpiration is the movement of water through a plant. It starts at the roots where capillary action pulls water in. Capillary action functions on the intermolecular forces discussed in 6.2.1 [3]. By having water inside the roots, water outside is pulled in by these intermolecular forces. This creates a “chain” of water that extends all the way up the plant's water transportation system called the phloem and leads to the leaves. Figure 6.3a shows the absorption of water at the roots by capillary action and Figure 6.3b represents the “chain” of water.

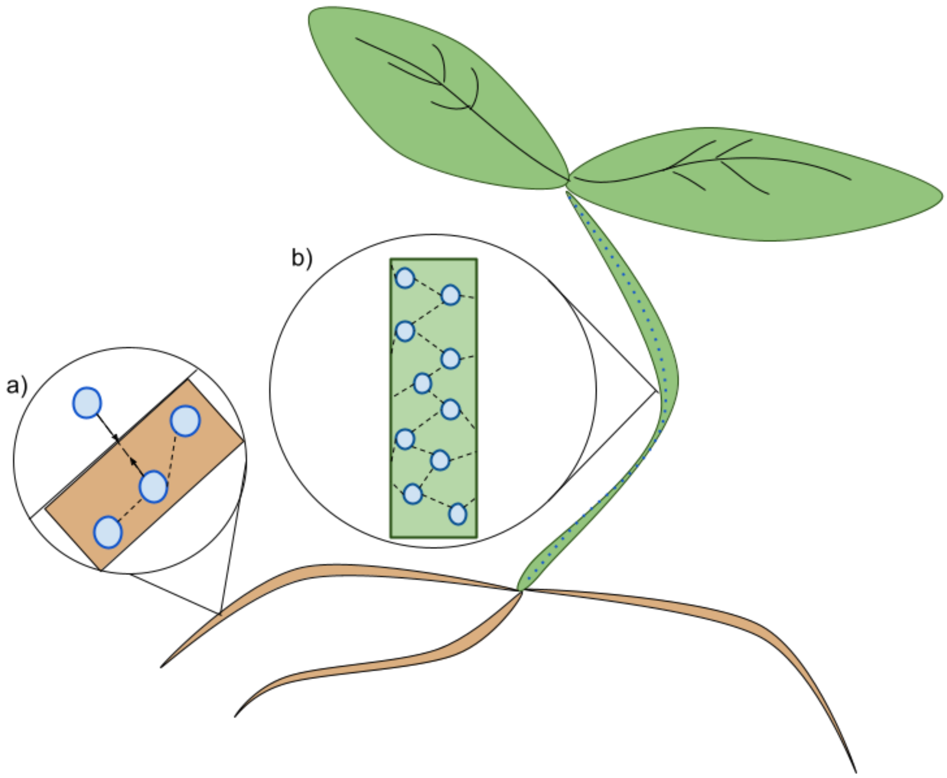

Figure 6.4: Capillary action in phloem [Joshua Gatto]

Once the water reaches the leaves, it can be used to regulate the plant's temperature [4]. If the ambient temperature becomes too hot, the leaf's stomata open up. This allows for water inside the leaf to evaporate into the atmosphere, removing some of the heat from the plant body. Figure 6.4 shows two stomata cells, one that is closed (Figure 6.4a) and another that is opened (Figure 6.4b).

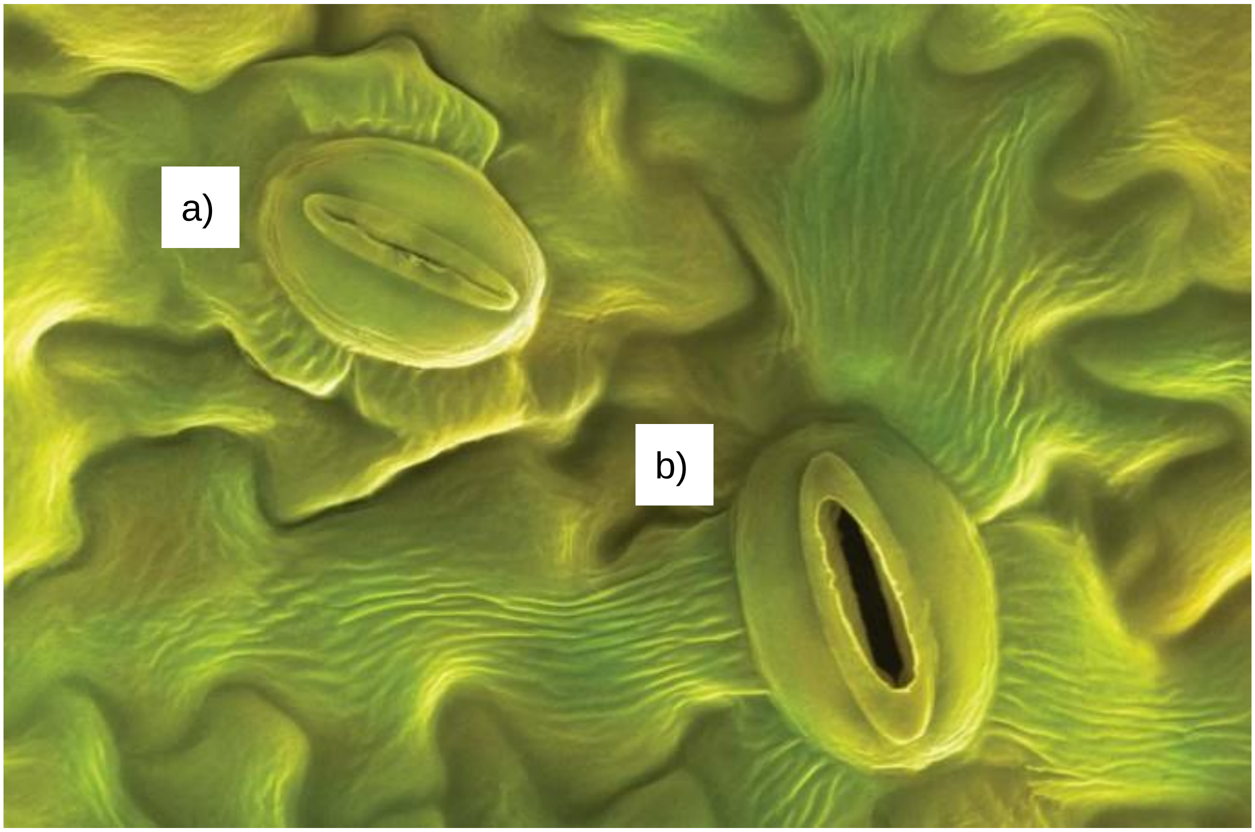

Figure 6.5: Open and closed stomata [5, modified]

6.2.3 Heat capacity

Water is effective in temperature regulation due to its high specific heat capacity. Table 6.1 below shows the specific heat capacities of a few substances, as well as water, arranged from highest to lowest. Water in its liquid state is much higher than any other substance on the list.

Table 6.1: Specific heat capacities of some common substances [6]

Substance	Specific Heat (J/g°C)
Water (l)	4.18
Water (s)	2.06
Water (g)	1.87
Ammonia (g)	2.09
Ethanol (l)	2.44
Aluminum (s)	0.897
Carbon, graphite (s)	0.709
Copper (s)	0.385
Gold (s)	0.129
Iron (s)	0.449
Lead (s)	0.129
Mercury (l)	0.140
Silver (s)	0.233

Specific heat capacity determines the amount of heat energy that a molecule can absorb [7]. Water's heat capacity can be calculated using the Equation 1 for specific heat below:

$$Q = mc\Delta T \qquad (6.1)[8]$$

where Q is the thermal energy in joules (J), m is the mass in kilograms (kg), c is the specific heat capacity in joules per kilogram degree Celsius (J/kg * °C) and ΔT is the change in temperature in degrees Celsius (°C). The specific heat capacity is the ratio of thermal energy to increase in temperature. In other words, how much energy is required for 1kg of that particle to increase the temperature by 1°C. For example, if 1kg of water is increased by 30°C, the energy required can be calculated using Equation 2.

$$Q = (1kg)(4.184J/kg * °C)(30°C)$$

$$Q = 1.25kJ$$

The energy absorbed by the water is 1.25 kJ. Water has the capability to absorb so much thermal energy due to its intermolecular forces being very strong as 1kg of water requires 2.25 kJ of energy to change phases. In industrial application, water's cooling effect is used to cool milling tools that undergo large changes in temperature due to constant friction.

6.3 How Evapotranspiration can Reduce the Urban Heat Island Effect

Green roofs employ the scientific theories and benefits discussed in Section 6.2. By absorbing the thermal energy from the sun and repurposing it to cause a phase change of water from liquid to gas, thermal energy is removed from the atmosphere. While these benefits are intrinsic, they are not automatic. Green roofs can be thought of as a system, where energy and matter is put in and cooling is received. For green roofs to maximize those benefits, a set of conditions should be satisfied. The first condition is heat [9]. In Section 6.2.2, it is explained how temperature can affect the stomata. By increasing the temperature, stomata cells will open up to allow for more transpiration, and thereby more cooling to occur [10]. As seen in Section 6.1 city environments can be up to 5℃ hotter than urban environments, creating an optimal environment for transpiration. Another condition to consider is water. In stressful situations, where water is low, a plant’s stomata will close to minimize water waste. When constructing urban environments, water drainage must be maintained by infrastructure to keep the streets dry. By placing plants before infrastructure, plants can be ensured water, just as in Figure 6.5 below.

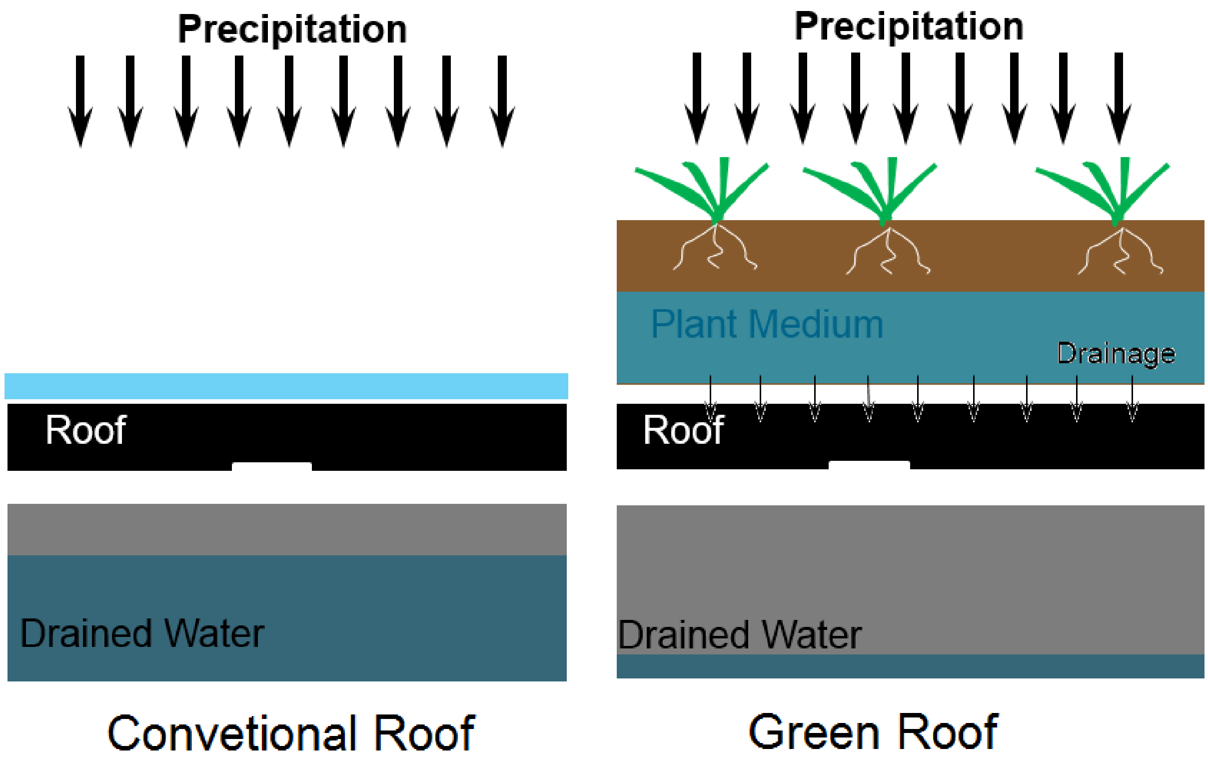

Figure 6.6: Regular roof vs green roof drainage methods [11]

Naturally, cities seem to be a fitting environment for green roofs to maximize the cooling effect of evapotranspiration. Over many green roofs in a city, it is expected that ambient city temperatures could drop by as much as 5°F [12]. For those reasons, cities, like Toronto, have instituted laws that require buildings with large enough surface area to incorporate green roofs into the design in an effort to reduce the urban heat island effect [13]. In closing, green roofs can provide the benefits of evapotranspiration to help reduce the urban heat island effect. All the factors for the cooling effect of transpiration are provided in nature; water falls from the sky, the sun heats the earth, plants transpire. By putting plants back into the equation, they are providing a cost-free, self-renewing cooling effect.

Glossary

Bonds – A small but present magnetic force attracting matter [14].

Phloem – The structure inside the plant's body that facilitate the transport of water [15].

Stomata - The pores on a plant's leaves that allow for the exchange of air and water vapour [8].

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