Heat Island Effect - Rotterdam

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Summary

The trend report describes the stress Urban Heat Island (UHI) on the city of Rotterdam located in the Netherlands. The UHI refers to the phenomenon where the temperature in the city is higher than the temperature of the surrounding areas. The UHI is caused by the change of land use. The describes solutions to this problem are to use urban vegetation. Another solution is the use of materials with a higher albedo. The last solution that is described is the change of the design of the urban area. Knowledge questions as well as discussion questions are provided as well.

Keywords: urban heat island, Rotterdam, urban vegetation, albedo, design of the urban area.

Contents

1. Problem statement

In the beginning of August 2020, the Netherlands suffered under a heat wave lasting for 13 days [1]. Numerous heat records were broken. Due to climate change, the expectation is that heat waves will be more regular and more extreme [2]. Besides this, more and more people live in urban environments, where the temperature can be 2 to 8°C higher than in the surrounding countryside [3]. This results in health and well-being issues for the citizens. In this problem statement, the Urban Heat Island (UHI) is explained. Also, the effects of this phenomenon on the urban network are described. Moreover, the possible development of this stress under climate change is discussed. The last part covers the ethical consequences of the UHI. The selected city is Rotterdam.

Rotterdam is a city located in the Netherlands with over 650 thousand inhabitants. It is the second largest city of the Netherlands. It also has an important national and international function due its harbor. Therefore, the resilience of Rotterdam to the UHI effect is interesting to investigate.

The term Heat Island refers to the situation where the temperature in a specific area is higher than in the surrounding area. When the heat islands are located in the urban area, the term Urban Heat Island (UHI) is used [4]. The temperature in the city is thus higher than the temperature of the surrounding areas. The UHI is caused by the change of land use. Vegetation is reduced and therefore also the amount of evaporation. Moreover, the amount of dark surfaces with a low albedo increases in a city, which results in a higher surface temperature. Albedo is discussed in more detail in Chapter 2. The production of heat in the city is also higher due to the anthropogenic activities [3].

The UHI effect mainly leads to an increase in sensible heat, but a reduction in latent heat fluxes due to the limited availability of vegetation which evaporates water and thus extracts heat from the atmosphere. Heat release during the night is limited [5]. The wind speed in cities is reduced to the increased roughness which prevents the cooling of the city during nighttime. The UHI is strongest during calm and clear nights [6].

The UHI effect, which causes persistent high temperature in the urban environment, affects the health of the citizens of a city [7]. Humans experience increased thermal stress due to the higher temperatures [5]. This leads to malfunctioning of the body which in the extreme case could lead to death. In the heat wave of July 2006 in Rotterdam, which lasted 16 days, statistically 1000 more people died compared to an average July [4]. Mostly elderly people are affected by this phenomenon.

The UHI effect can also cause issues in the ecological and environmental domain, mainly due to increased air pollution. Urbanization, the main cause of the UHI, leads to problems in air quality. Moreover, the UHI increases problems in air quality. The increased energy demand also leads to an increase in greenhouse gas emissions. This leads to a reduction in air quality. The strong temperature differences between the city and its surroundings also creates a re-circulation of air. This leads to an inversion which prevents the air pollutants to disperse upwards. Air pollution causes several health problems, like deaths, asthma and cancer [5].

An increased mean temperature with a decreased temperature difference between day and night, two measures of the UHI, lead to a higher water consumption. Part of this water is used to cool the environment, for example by using evaporative coolers [8]. The increased water demand could lead to economic and sustainability issues in the long-term.

Due to the higher temperature in the city, the cooling energy needs to increase, most apparent in air conditioning systems. This leads to a decrease of temperature inside buildings and a reduction in mortality rate [9]. But, it also results in a further increase in the production of heat and electricity demand. More generally speaking, for 1°C increase in temperature, research shows that the electricity demand increases with 2 to 4% [3]. Also, the peak energy demand increases.

The relationship between global warming and the UHI effect is difficult to describe. Air temperature in cities tends to increase faster than the average increase of the mean temperature of the planet. But, the intensity of the UHI might stay the same when the changes between the temperature in the city and its surroundings doesn't change due to a rising temperature of the Earth. It is even possible that the UHI intensity decreases due to global warming. This is possible when certain variables, like weather types, change in favour of a less intense UHI [10].

Local variability makes it also difficult to explain the development of the UHI under climate change predicted by global models.The urban area is difficult to model and the availability of data is low for the required resolution. Also, when the urban area is located in a relatively warm part of the Earth, the UHI effect will increase the usage of air conditioning, which leads to a more intense UHI. However, in colder areas of the Earth, an UHI will reduce the energy used for heating and thus has different consequences [10]. It could even lead to a reduction in energy usage because less energy is needed for heating a building.

Another remark is that the development of urban areas is not known. In the past, more and more people settled in cities. Nowadays, cities tend to grow into large metropolitan regions. This will reduce the UHI intensity, but increase the area that is affected by the higher temperature [10].

The UHI effect may lead to very warm temperatures. This increases the use of energy. This is not very sustainable on the long term, because this could enhance the effects of climate change, which can result in an even more intense UHI, but also higher global temperatures. A lot of research is conducted to provide sustainable alternatives. These alternatives are for example, greenroofs and ponds. These solutions might also result in a more livable city and is thus beneficial for the health of the citizens.

Considering health and well-being, the UHI can lead to severe health problems which may lead to death. The city should be prepared for extreme temperatures and provide solutions and opportunities for cooling. However, these solutions must be sustainable to prevent even worse events and accessible to everyone.

The UHI effect may also cause inequality among citizens. Some, probably richer people, might have access and can afford air conditioning, while others might not. This could even result in a higher surface temperature because air condition creates heat. This makes the alternative solutions to cool the city attractive because some of them are provided by the city and do not belong to a certain household. Moreover, they tend to not generate heat. This increases the equality in terms of options for cooling during an UHI and results in a overall decrease of heat, not just locally.

An overview of the causes and consequences of the UHI discussed above on the Social-Techno-Environmental system is given in Figure 1.1.

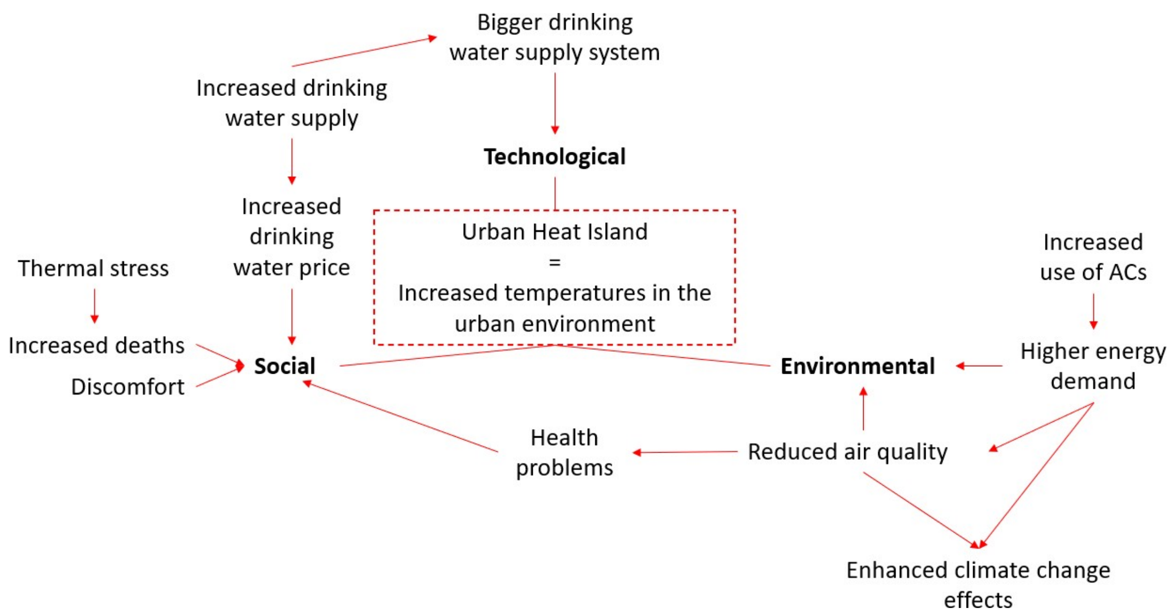

Figure 1.1: Overview of the causes and consequences of the UHI on the STE system

2. Solution strategies

To make and keep the city a livable place to spend your time during hot and cold days it is important to develop solution strategies to decrease the effect of the UHI. In this chapter, several solution strategies and their results are presented. Also, the ethical consequences and the way the solutions can be monitored is discussed.

The goal of the solutions to the UHI problem is to keep the temperature difference between the city and the surrounding rural area as small as possible. It is obvious that the solution of a rising temperature in the rural area is not the one we are looking for. Diminishing the detriments of climate change is also important, which excludes this option. Cooling the urban area is beneficial to the health of its citizens. Moreover, lower temperatures reduce the cooling demand of buildings which lead to energy and peak power savings.

The first solution is the use of urban vegetation. This means the increase of vegetation in the urban area. It can be achieved in different ways, for example the use of green roofs and vertical greeneries [11]. Vegetation cools the environment in two ways. The first possibility is by providing shade. It also has a cooling effect because vegetation extracts heat from the environment when water is evaporated through the leaves. Research shows that the difference between the urban area and a small park can be up to 3°C [12]. However, the effect is significantly higher at the surface than for near-surface temperatures. When the surface area of green roofs increases, the decrease of surface temperature is almost linear [13]. The more water is available for the vegetation, the stronger the cooling effect is. Another advantage of increased vegetation is the increased albedo compared to normal urban surfaces. The consequences of an increased albedo are discussed in more detail in the next paragraph. The disadvantage of this solution is that it is costly. The development of green buildings can be up to 9% more expensive [14]. Their construction can also be more complex.

Another solution is using materials in the city that have a higher albedo than the currently used materials. Albedo, a value between 0.0 and 1.0, is the ratio between the reflected radiation and the incident radiation. Thus, the higher this value, the more incident radiation is reflected back to the atmosphere. This leads to lower surface temperatures. The darker the surface, the lower the albedo and thus the more radiation is absorbed by the specific material. Options for increasing the albedo of a city are painting surfaces, like roads and roofs, white and increasing the amount of vegetation. An albedo increase from 25% to 40% leads to a temperature drops of 1-4 °C. One should take into account that a city consisting of white roads might not be pleasant for the eyes of its citizens. However, there are also plenty of other surfaces that could have a white color and are less visible, for example roofs. [15]

The third solution that is discussed is the use of open waterbodies in the urban area. One can think for example of ponds and fountains. Waterbodies can have a cooling effect since evaporation of water extracts heat from the environment. This results in a lower air temperature. Research shows that waterbodies can cool the environment during the day. However, since the heat storage capacity of these waterbodies is large, the diurnal temperature cycle is reduced. This means that during the night, the areas around the waterbodies experience a higher temperature than in the case that there is no waterbody present. Therefore, the use of waterbodies to cool the environment turns out to be not a very good solution to the UHI effect when temperatures during the night remain high as well. [16]

The last solution that will be given attention is the change of the design of the urban area. The design of the city influences the absorption of solar energy and the formation of winds, and thus the UHI. Several measures can be taken to cool the urban area. The first one is to use vegetation to shade buildings. The advantage is that in winter, the trees have no leaves and thus do not have the cooling effect they have in summer. Another option is to design with the wind, by designing the city in such a way that wind speed is enhanced. This results in dispersion of hot air and air pollutants [17]. When planning the urban area, one also can think of how air conditions systems should be designed. These systems can enhance the UHI effect, but also lead to a more comfortable climate inside buildings. Therefore, the heat produced by the AC-systems should be released somewhere else than into the air. One option is to use a nearby river to transport the heat away from the city [9].

The ethical implication is that it might be the case that not all solutions are available to everyone since they are expensive or cannot take place at their specific property. Green roofs and materials with a higher albedo can be quite expensive and therefore only affordable for the more rich people. This might result in clusters of green and cooler areas in richer parts of the city. A solution might be to create parks in the city, which are accessible for every citizen. Moreover, the use of ACs can result in higher surface temperatures. This, people working inside the building experience a pleasant temperature at the cost of the people outside the building. This should be taken into account when placing AC-systems. The other solutions are for the whole city and therefore available to all citizens.

When solutions are applied, it is also important to monitor the effect of these solutions to be able to answer the question if the solution actually works. Monitoring of the solutions can be done in different ways. One option is to place temperature sensors at specific places in the city and also in the surrounding rural area. This data makes it possible to compare the temperatures of the city and the rural area, but also to the previous situation without the solution in place. This option provides reliable temperature data, but can be quite costly. Also, there is a limited amount of data available when there are no temperature sensors in place before the solution is implemented. Another option is to use satellite images which provides surface temperatures. These images should have a high spatial resolution since the temperature in the city is highly variable. The obtained temperatures should also be compared to a selected rural area to see what the effect of the solution is. Using satellite images has some downsides. Its spatial resolution comes at the cost of its temporal resolution and cloud cover makes it sometimes difficult to obtain a valuable measurement [18]. The advantage of this option is that there is a lot of data available at low costs.

3. Links for further reading

For further reading, the following articles are advised:

- *The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete* [3]. This article provides a nice introduction to the UHI effect and also provides an overview of the existing solutions. Future methods are outlined as well.
- *Spatial variability of the Rotterdam urban heat island as influenced by urban land use* [19]. This article provides an overview of collected data to describe the UHI. It also explains the link between UHI and land use. The outcome of this article is a map where areas at risk during a heat wave are highlighted. This outcome can be used to plan mitigation strategies.
- *Refreshing the role of open water surfaces on mitigating the maximum urban heat island effect* [16]. This article discusses the solution of open water bodies. Its conclusion is that these do not have the desirable and expected effect.
- *Mitigation of the Urban Heat Island effect by using water and vegetation* [12]. This article provides measurement results of the UHI for the city of Rotterdam, the city of interest. Also, the effect of several solution strategies are measured.
- *Residential cooling loads and the urban heat island—the effects of albedo* [15]. In this paper, the solution strategy of a higher albedo is investigated using a model. The outcome can be used to further develop this solution.

4. Understanding questions

This section provides five question to test your understanding of the UHI effect. The answers are provided separately.

4.1. Questions

Try to answer the following questions.

1. What are the causes of the UHI?
2. When and why is the UHI effect strongest?
3. Why is the use of vegetation a solution to the UHI effect?
4. Would you choose a open water body to cool the city? Explain your answer.
5. What are the possible techniques to monitor the solution strategies?

5. Discussion questions

The following questions to start a discussion are provided:

- Would you consider the UHI effect as a positive, negative or neutral effect?
- If a solutions cools one part of the city, but results in a higher temperature somewhere else in city, would you implement this solution?
- How big do you consider the problem of the UHI?

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