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HEAT ABSORPTION COOLING AS AN OPTION FOR SUSTAINABLE AIR CONDITIONING OF HOUSEHOLDS

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Abstract: Urban planning and architecture are often influenced by the sun. Especially in the colder countries of Europe, like the Netherlands, houses are mostly designed for cooler periods: well insulated, large windows and living spaces oriented on the south, small windows and less-used rooms on the north, etc. Due to climate change (and improved insulation) the main issue of in-house climate control is no longer just to keep the house warm in winter but to keep it cool in the summer.

Due to extremely warm summers households are increasingly purchasing energy-intensive air conditioners to keep their houses cool. Air conditioners are relatively cheap and easy to install, but consume much electrical energy which increases the use of fossil fuels and additional exhaustion.
This paper looks at ways to reduce the need for (energy for) cooling of houses in passive as well as active ways in summer. For passive cooling it for example proposes adapting spatial planning, design of houses, construction materials and ventilation. For active cooling it describes heat pumps, heat absorption and even waste heat as a means for cooling to reduce the need of electricity. It could have considerable advantages to use waste heat from industry in summer for cooling, to prevent new peaks in electric power consumption and to avoid discharging heat in rivers or coastal waters possibly causing large ecological damage.

1. Introduction to urban heat problems

Climate change is a fact. As a consequence zones that had modest climatic conditions, will suffer from higher temperatures. This effect has advantages during winter as it will reduce the need for heating. However, as summer temperatures will rise it will create nuisances during summer especially in urban areas where summer temperatures are highest because of the urban heat island effect. The heat might take an increasing death toll; diminish health conditions and increase economic costs due to worsening labor conditions.

As a result, more air conditioners might be installed, and their use might increase. This will create an additional demand for electricity, additional release of CO_2 and sometimes also an additional release of heat in the urban area itself. This paper explores possible options for cooling that do not make the problem worse. The main question is whether absorption cooling, that uses (industrial) waste heat, is a viable alternative?

Climate Change

The rising levels of CO_2 in the atmosphere, caused by the incineration of fossil fuels, reinforce the naturally occurring greenhouse effect. Over the past 150 years, the concentration of CO_2 in the atmosphere has risen from 290 to 345 parts per million. Various other gasses that are released in the atmosphere have similar greenhouse effects. The Intergovernmental Panel on Climate Change concludes that the average increase in surface temperatures over the 20th century was 0.6 $^oC \pm 0.2$ ^oC (IPCC, 2001). A further increase is predicted ranging from 1.4 to 5.8 ^oC in the year 2100. This climate change does not have the same magnitude around the world. In the moderate climate zones of Middle and Northern Europe, the average temperature increased between 1970 and 2004 between 1 and 2 ^0C (IPCC, 2007).

Urban Heat Islands

Temperatures that are measured by weather stations are often not representing air temperatures in downtown areas of cities. Weather stations are often situated in the countryside, which has often considerable lower temperatures. This temperature gap is at maximum under conditions of sunny weather and in the late afternoon. The gap might be 7 ^0C at maximum. This phenomenon is also known as the ‘urban heat island effect’. Climatologists have studied this gap extensively (Cf. e.g. Landsberg, 1981) and for various cities like London (Watkins et al, 2002) and New York (Rosenthal et al., 2003). Urban climate studies have become a new sub discipline of climatology (Arnfield, 2003).

Climate change might even slightly strengthen the urban heat island effect. A model that was based on historical data for London was used to make predictions. The annual mean night time heat island effect was predicted to increase by 0.26 ^oC at maximum in 2080. Although this is considerable less than the predicted London temperature increase (3,5-4 ^oC at maximum) one should take into account that that this is an annual average and so the increase of the urban heat island effect could be far greater during heat waves (Watkins et al., 2007).

Figure 1 - Sacramento's summer heat in false-color infrared image. Taken June 29th, 1998 by Urban Heat Island Pilot Project (UHIPP). Green areas are about 30 °C and white areas about 60 °C http://science.msfc.nasa.gov/newhome/headlines/essd01jul98_1.htm

The urban heat island effect has several causes:

- In urban areas, energy consumption per area is much larger then in the countryside. Transport, lighting, machinery consume energy that is ultimately all transformed into heat.
- Buildings and pavement is generally not reflecting sunlight. It therefore heats up by sunlight and only gradually cools down in the evening and night.
- Vegetation and open water is scarce often in downtown areas. Vegetation and open water cool their environment by evaporation. Vegetation only has a limited heat capacity. Hence it is unable to store much heat.

The urban heat island effect is nothing new. It causes the soil under cities to gradually change its temperature. In general temperatures of barren soil are constant at depths over 1 meter. If soil is homogeneous and its surface barren, the lowest soil temperature is at the depth where the seasons have no influence anymore. This can be understood by the constant flow of heat from the Earths' core to the surface. An effect of climate change is that this minimum has moved somewhat deeper (Buik, 2004). Temperature measurements in the soil under cities confirm urban heat and even reflect some of the urban history as the depth of the minimum temperature is greatest under the oldest parts of a city (Ferguson/Woodbury, 2004).

Effects of higher urban temperatures

Higher urban temperatures create less demand for heat during winter cold. However, as climate change proceeds, this effect is overshadowed by the problems of summer heat in urban areas.

In general, if humans are subjected to temperatures over 27°C, various health complaints develop: People are more tired and are less able to concentrate. Especially patients that suffer from cardio vascular diseases are subject to an additional risk of hart failure. At higher temperatures, the body might be unable to get rid of access heat. The symptoms might be irritability, thirst, exhaustion, dizziness and sometimes muscular spasms. The prolonged subjection to elevated temperatures might induce strokes. The occurrence of these symptoms

is not only related to heat. Moisture and wind (Kalkstein/Sheridan, 2003) and citizen’s behavior (clothing and activity level) also play a role. Groups with elevated risk are elderly, children, poor people, and patients of hart- and lung diseases.
Estimates regarding number of heat victims are hard to make. A main reason is that heat waves often coincide with the occurrence of summer smog (ozone at street level) and increased levels of fine particles or particulate matter (smaller than 10 µm). Clearly, there are considerable more deaths during heat waves (figure 2).

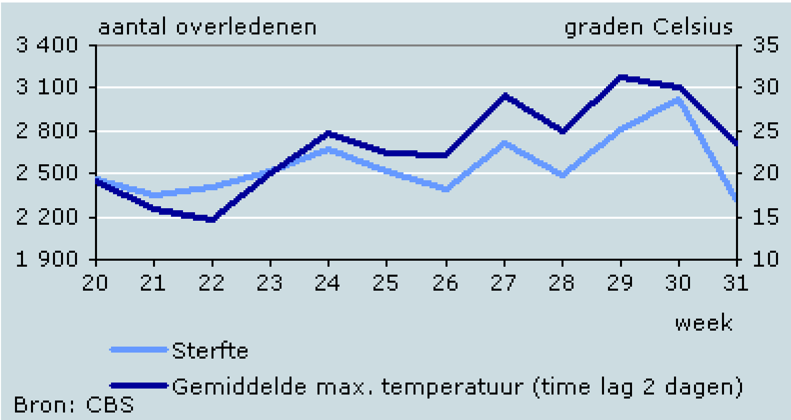

Figure 2 - Weekly people deceased in the Netherlands and Mean average temperature, summer 2006 (webmagazine CBS, 2006)

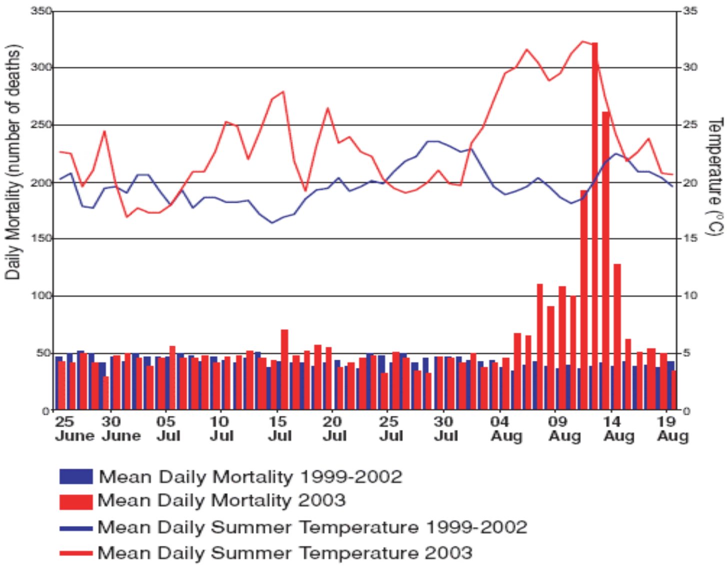

Figure 3 - Daily Mortality Paris 2003 (IPCC presentation, www.ipcc.ch)

Various other analyses of health effects of heat waves can be found in Kirch/Menne/Bertollini, 2005. A UK study analyzed the relationship between mortality, air quality and elevated temperatures for several UK cities. It concluded that between 21 and 38 percent of the victims were probably not caused by heat, but by smog and particulate matter (Stedman JR., 2004). Establishing the cause of death is of course crucial for the decision on effective counter measures. Cooling might only be effective if heat is the cause of death.
The growing death toll of heat waves has prompted some counter measures. For example the Red Cross has created plans to prevent casualties by heat waves. In North America and Southern Europe, air conditioners were already in wide use. Recently, also many Northern

European citizens start buying air conditioners probably not only by fear of health risks but also searching for higher comfort levels. Installing an air conditioner is an effective measure that is easy to implement. For 200-300 euros, a plug and play air conditioner can be purchased.
The electricity consumption of a small air conditioner (1 KW) that is not extensively used (200 hrs/year) will be 200 kWh. This will create 87 kgs of additional CO_2.[1] Moreover, the 200 kWh will end up in the urban atmosphere, causing some higher urban temperatures during heat waves.

2. Options to reduce urban heat

What are the options to reduce urban heat, or prevent its effects, that do not involve additional energy consumption and emission of greenhouse gasses?

Behavioral measures

Administrative measurements are often cheap. Information and administrative rules could reduce some burden:

- Close blinds in time;
- Moisten flat roofs in order to stimulate evaporation and solar reflection;
- Ventilate buildings at coolest hours, close ventilation at hottest hours;
- Reduce heat production by switching of unnecessary equipment and lights.

Parks, Trees, Meadows

Vegetation reduces urban heat at street level and has other advantages:

- It provides shade;
- It increases evaporation which has a cooling effect;
- Deciduous trees that loose their leaves in winter, do not block the heat of the winter sun;
- Vegetation cleans the air and dims noise.

Vegetation also has disadvantages:

- Trees might fall down by storm winds.
- It might attract wildlife (birds, insects) that is considered as nuisance.
- Trees affect the foundations of buildings, roads and other infrastructure
- In places where trees are needed most, space is limited
- Higher maintenance costs for grass and bushes (mowing, cutting back, irrigation, etc.)

Vegetation is often much appreciated by the city dwellers. Small scale wildlife is very often considered as an enrichment of urban life (Cf. BBC website, 2007).

Water

Water surfaces in urban areas also have a cooling effect:

- Water reflects more sunlight (~ 30 %) than most building materials (5-10 %)
- Water evaporates at the surface, thereby cooling the humid air above the water surface. For the cooling effect, wind is important as it spreads the cooler air and replaces the humid air with dryer air that is able to sustain the evaporation.

[1] NUON’s elektricity product mix. (http://www.nuon.nl/nl/fs_main.html?L1=overenergie&L2=stroometiket)

This cooling effect was proven at an experiment in downtown Bucharest. A small pond (4 * 4 m) had a cooling effect of about 1 °C at a height of 1 m, at 30 meters distance. The surrounding surface was asphalt and concrete (Robitu et al., 2004)
A disadvantage of water might be that various biological processes and microbes might develop if the water does not circulate. Running water flows are therefore best for cooling as they might also bring cool(-er) water into the urban area. Ponds might make the urban environment more attractive and might be used to store part of the water in periods of heavy precipitation. Creating space for ponds is usually a problem in existing urban areas. When new estate is established water could be 'forced into the spatial plans' by the national government as is done nowadays in the Netherlands. But in existing down town areas space problems force us to consider other options than vegetation and water.

Spatial Planning

The spatial structure of urban areas has a strong influence on urban heat. The density of buildings determines the possibility of cooling winds. East-West orientation of buildings might create a larger solar influx into buildings, while facilitating East-West wind flows and blocking North-South winds.
The density of buildings roads, parking lots and pavements determines the solar influx of the area as these materials have a low reflexivity. At the other hand, if there are more tall buildings the solar radiation induced heat builds up at the roofs and facades of these buildings. As these buildings have a considerable mass that acts as a heat buffer the ground temperature is less affected.
As result, from the perspective of urban heat, there is a worst case for urban typology. Watkins et al. (2002) identified that these were medium density urban areas, with mainly hard surface and a wide gorge (height buildings/width of street between 0.3 and 0.5), a typology that is rather common in many European cities.
An extra problem is that for long time spatial planning has been aimed at utilization of 'passive solar energy', i.e. optimal inflow of solar heat in winter. However, at the latitudes of the main cities in Europe and North America, the positive effects of inflow of solar heat in winter are far less than the costs of cooling in summer.

Roads

Pavements of roads and parking lots reflect little sunshine. The albedo values (reflection coefficients) are generally between 4 % (new asphalt) and 16 % (Heat Island group, 2007). Asphalt roads can be coated to increase their albedo to 50 % but this affects traffic and probably traffic safety. Experiments have been carried out to cool roads by fluids in a piping system integrated in the road. The hot water might be stored and used in winter to prevent freezing of the road. Main driver for these systems is maintenance costs as cooler roads in summer are less damaged by heavy traffic. Next to that the heating in winter also prevents surface damage from frost and it saves money for de-icing. If such systems would be applied on a large scale in urban areas, they could have a cooling effect in summer and a heating effect in winter. In Europe, this technology is introduced by Arcadis under the name of Winnerway (Arcadis: 2007).

Roofs

Roofs could play an important role in bringing building temperatures down. The albedo of bitumen roofs is very low. It can be increased by coatings. Various materials like paints and special tiles can be used to increase the roof albedo. These measures are relatively cheap and

the investments are soon returned by lower electricity costs for air conditioning. Depending on the slope of the roof, cleaning might be required to keep the albedo high (EPA, 2007)
Covering a roof with water is effective but requires a flat roof. Moreover, it requires considerable maintenance. Vegetation on roofs also requires some maintenance. Moreover, the roof must be able to carry the weight of the soil and the vegetation (plus winter snow, and a safety margin), which also accounts for covering a roof with water. Therefore, these roofs are generally only appropriate if the span of the roof is not large. Vegetated roofs might be attractive for the inhabitants of a building. Moreover, they keep the temperatures of building materials more constant, thereby preventing heat induced cracks (EPA, 2007).

Building Materials

Depending on building orientation, the facades of buildings have an important effect. Higher albedo values are important here too (see: Hien et al., 2007) for a recent overview). The albedo of grey stone is 20 %, concrete is 33 %, red brick has 44 % but plaster can have an albedo up to 73 % depending on the color (Novem, 2007).
Higher buildings contain more mass, and thereby have more stable temperatures. Moreover, the solar influx is at larger distance from the street level. More mass in buildings can help to keep building temperatures down especially if it is combined with smart building management, i.e. ventilating the building at night and thermally insulating it to prevent influence of higher outside temperatures.

Utilization of Solar Influx

Thermal solar collectors convert the solar influx to heat. If the heat is transferred and stored, for example in aquifers, the heat might be used in winter for heating. In summer such a system might have a cooling effect as it transfers the heat while replenishing it by cooler water. Naturally, the effects of such systems would only be of relevance if they were applied on large scale.
Photovoltaic (PV) solar cells convert solar radiation into electricity. As PV cells cannot operate under conditions of too much heat, there is a cooling air gap between the PV cell and the roof. In this way PV cells create a parasol for the roof. As PV cells are still rather expensive their use is limited and generally only covers small parts of a building. However, if they will be far more widely used they might have a cooling effect on buildings.

3. Technical options for residential cooling

If buildings are too warm cooling is unavoidable. To cool a building active and passive cooling could be used. Passive cooling is energy-extensive and could for example be done by ventilating buildings at night when outside temperatures are rather low and keeping all windows closed at day-time. To effectively implement this measure one needs considerable ‘building-mass’ that can accumulate heat and cold to keep inside temperatures constant. An addition to this is ventilating buildings by using the cold air in the basement to cool the building; in this case usually a heat exchanger is needed as the air quality of the basement does not meet the air quality requirements.
For housing usually active, energy-intensive, cooling is used. The most energy-intensive one is the air-conditioner. But there are some technologies on the market or in development that use less energy.

Underground Heat/Cold storage and FIWIHEX

The FIWIHEX, Fine Wire Heat Exchanger, is a very efficient heat-exchanger. By its high efficiency, it can use small differences between the heating/cooling medium and the air to be heated/cooled. Water of 10 °C can be used to cool indoor spaces. Heat/cold storage has thereby less losses. The larger amounts of hot water that are required can only be stored in aquifers. So FIWIHEX might heat buildings in winter and cool them in summer.
Pilot project are running nowadays in greenhouses in Holland. (Fiwihex International, 2007)
So far there have not been tests with domestic heating as a Fiwihex produces a soft noise that might be perceived as inconvenient.

Heat pumps

A really effective way of cooling a building is to use heat pumps. Usually heat pumps are used to heat building by using the temperature of low energy sources like air, ground water or surface water to produce water with a temperature that is high enough to heat a building by low temperature heating systems.
These heat pumps can also be used to cool buildings. In this case only the heat exchanger is needed to cool the building as the temperature of the ground water is low enough and the low temperature system of the building can be used to distribute the cold from the ground(water) through the building. This is a way of passive cooling (because the heat pumps are not used). But the heat pumps can be used for active cooling when more cooling power is needed.

Heat Absorption Coolers

An interesting technology to produce cold is the heat absorption cooler, which uses heat to produce cold without using a compressor like heat pumps do (energieprojecten, 2007) so it does not need electrical energy to produce cold. The absorption cooler can already run on relatively low-quality energy but has a very low coefficient of performance (CoP) compared to for example heat pumps (0.7 instead of 4.0). This means that heat absorption cooling is only interesting when the heat that is used is free or very cheap (cogeneration, 2007).

Using waste heat from district heating to cool houses

To reduce primary energy consumption of households a lot of cities in the Netherlands are developing heat distribution systems to link industries with cities to provide them with (waste) heat. In the Netherlands more than 100 PJ of waste heat is ‘thrown away’ by active cooling by the industry (ECN, 2007). Only the Rijnmond area of the Netherlands (corresponding with the port of Rotterdam) already produces about 37 PJ of waste heat (representing almost 2 Mton CO_2/year) could be used for heating instead of spilled (CE, 2002). This heat can be used to heat the houses as well as to produce hot tap water.
However, in summertime heat might be a real problem for power stations and refineries as they might be unable to release it to open water during prolonged heat waves. According to EU Directive 2006/44/EC, thermal releases are forbidden if the water temperature exceeds 28°C (Cyprinid waters) or 21.5°C (Salmonid waters). Moreover, heating of waters by discharges might not exceed 3°C (Cyprinid waters) or 1.5°C (Salmonid waters). As the heat demand of district heating systems is almost zero in these periods, increase in heat demand by absorption coolers might help refineries and power stations to get rid of their excess heat: a potential win-win situation.

So heat absorption cooling might be an outcome as it needs cheap heat to be feasible and the industry really needs to get rid of their waste water. An additional advantage is that no

additional electricity is needed to cool houses (which would have been needed in case of heat pumps or air conditioners) so power plants will be relieved and the amount of waste water will be reduced.
Another option could be to use the distribution system of districting heating reversely during summer. Households could be supplied with cold water for example derived from surface water (rivers or sea) or produced by a large scale (absorption-) cooler with the waste heat as input. But this implies that the system cannot be used for any heat or hot water supply in this period.

4. Pathways to reduce urban heat problems

A lot of options have been dealt with in this paper to reduce the need to cool buildings. As we want to avoid additional use of electricity 'passive options' will be the best way to challenge the heating of cities. So construction materials, spatial planning, shading and intelligent designing should gain attention. One can also think of consumer products that produce less heat to avoid inside production of heat.
But if passive options are not sufficient and we want to avoid further increase of electricity consumption and CO_2 emissions by growing numbers of air conditioners, we will need additional technologies to cool buildings that use less additional electricity than air-conditioners. Heat pumps will be the most efficient technology to use as they can also heat houses very effectively in winter. But if very cheap heat is available absorption cooling will be the most attractive option.

We sketched some interesting pathways that might contribute to reduction of urban heat problems and reduce CO_2 emissions but need further study. Especially using industrial waste heat for urban heating and cooling is a very interesting option as the waste water does not have to be (electrically) cooled, does not have to be disposed of and air-conditioners are avoided so no (additional) energy is needed to cool houses. The different options will undoubtedly involve various additional impacts on urban life which should be taken into account.

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