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RENEWABLE ENERGY SOURCES AND OTHER ENERGY TECHNOLOGIES AS A MEASURE FOR MITIGATING THE IMPACT OF URBAN HEAT ISLANDS.

SUMMARY

Urban heat islands (UHI) represent increase of temperature inside of cities in regard to their rural environment. Causes of their formation are diverse and multiple: reduced amount of vegetation and waterproofing of surfaces, changed radiation and thermal characteristics of materials, urban geometry. Consequences are also diverse and significant: increasing consumption of energy for cooling, negative impact on human health, deterioration of air quality. Conventional methods for mitigating their impact include reflective and green roofs and introduction of green and water surfaces in cities. Different renewable energy technologies can also have positive impact on urban heat islands, but at the same time they contribute to greater energy independency of cities what is goal of future urban development. Proposed and described technologies are solar cooling, ground-air heat exchanger, passive cooling, solar pond.

Key words: ground-air heat exchanger, passive cooling, renewable energy sources, solar pond, urban heat islands

1. INTRODUCTION

Cities around the world are facing growing problem of urban heat island, UHI, a temperature increase within the city with respect to its rural surrounding. This problem becomes more frequent as consequence of climate change as heat waves becomes more frequent and prolonged, although there are multiple causes for UHI occurrence. Consequences of UHI are also significant and diverse: negative impact on human health during summer months, and on the other side – increase of energy consumption for building cooling – which is contrary to European directives of energy consumption decrease.

Urban space cannot be longer observed only through its functional and aesthetic role. In urban planning more and more prominent becomes energy component because of interdependence of urban heat islands and energy consumption. Goals are energy independent cities developed on ecological principle, pleasant for life of humans and other living creatures. While accessing these goals, renewable energy sources can help us in achieving this idealized city image to which we definitely should tend.

2. URBAN HEAT ISLANDS

Built environment has significant impact on air temperature in the cities which is significantly higher with respect to rural and suburban surrounding (Figure 1), This phenomenon is called urban heat island and it is one of the most investigated effect of urbane climate. Urban surfaces and structures absorb sun heat during the day and emit it during the night. An average annual temperature of cities with more than one million inhabitants is typically from 1 to 3 °C higher with respect to their surroundings [1]. During bright and calm summer nights this difference can increase even up to 12 °C, thus creating extremely unpleasant atmosphere for urban population, Consequently, these higher temperatures increase cooling energy needs and increase peak electricity consumption because most of the cooling devices use electricity.

An energy balance equation for flat, horizontal and homogenous surface is given by (1):

$$(1 - a) \cdot I + L + Q_F = H + \lambda E + G \quad (1)$$

where a - surface albedo (ratio of reflected and incoming radiation), I - incoming sun radiation, L - net value of longwave radiation, Q_F - anthropogenic heat, H - convection heat, λ - latent heat of evaporation, E - evaporation quantity and G - conduction heat.

The left side of equation represents thermal gains, and the right side of equation thermal losses. Every part of energy balance equation is changing in urban surrounding and contributes to formation of UHIs. Main causes, processes and belonging quantities from equation which they affect are listed in Table I.

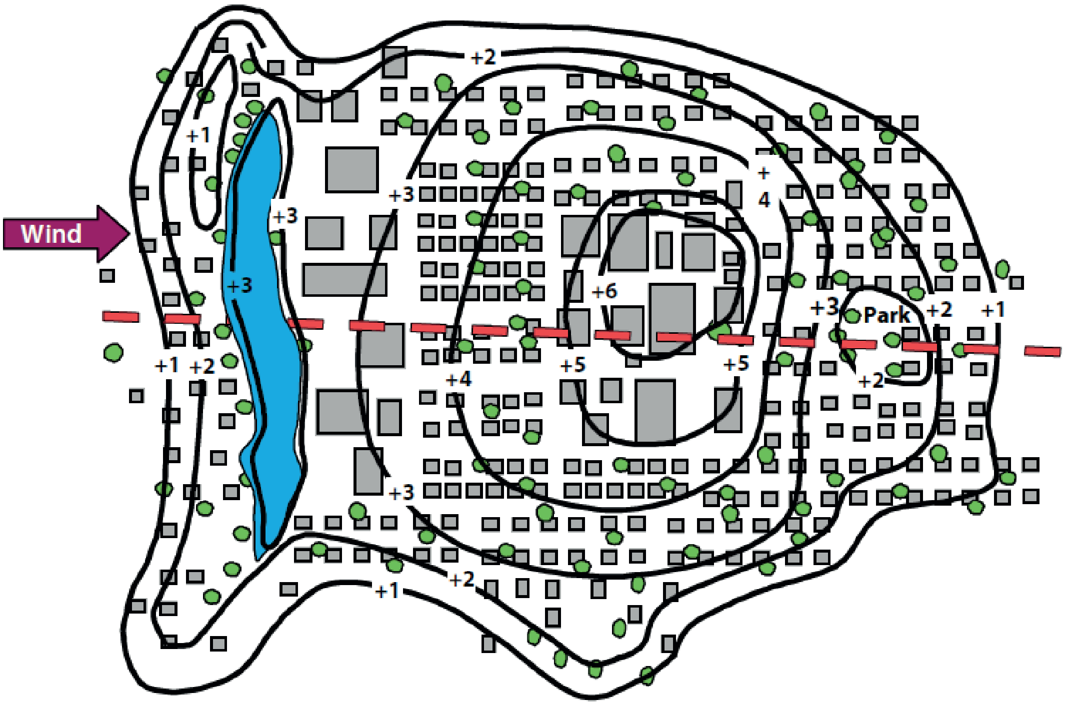

Figure 1 Isothermal map of nocturnal atmospheric urban heat island [1]

Table I Occurrence causes of urban heat islands and corresponding processes

Causes	**Members of energy balance equation**	**Corresponding processes**
Decreased amount of vegetation and impermeability of surfaces	λE	Decreased latent heat of evaporation
Changed radiation and thermal material properties	G, a	Increase of absorption and thermal capacity of surfaces
Urban geometry	I L H, λE	Multiple shortwave reflections Decreased loss of longwave radiation (smaller sky-openness coefficient) Decreased wind speed
Anthropogenic heat	Q_F	Cooling and heating of the buildings, industry, traffic
Air pollution	L	Increased absorption and re-emission of longwave radiation

The goal is to decrease thermal gains and to increase thermal losses. From the thermal balance equation, we can extract main factors on which we can affect: surface albedo, anthropogenic heat and evaporation quantity.

Considering that free surface in cities is quite limited and of high economic value, it is relatively hard to implement large projects of mitigating influence of heat islands on earth surface. Therefore, the main, conventional methods in combating urban heat island are the following: cold or reflecting roofs and green (or live) roofs. To these two methods we need to add and the third method which is connected to earth surface, and those are green and water surfaces.

Despite few positive effects of urban heat islands during winter months (smaller energy consumption for heating, ice and snow melting), much greater and more serious are negative consequences: increase of energy consumption for cooling, impact on human health, poorer air quality, increase of rainwater temperature.

3. INTERDEPENDENCY OF URBAN HEAT ISLANDS AND RENEWABLE ENERGY SOURCES

While fighting negative impact of urban heat island, we need to bear in our minds broader perspective – especially sustainable development. Can we, by lowering their impact, at the same time contribute to higher energy independence of today cities? Cities, during their existence are transforming and developing and they are never finished, so that today urban developers start to think about the cities as complex biological and natural system analogous to self-sustained living organism. Demand for energy and free space will continue to grow, also as material consumption and waste generation. At the same time, economy of size in cities gives a chance of increasing renewable energy profitability.

In order to lower the impact of urban heat island, urban communities are focused on changing characteristics of urban materials and increasing green surfaces, while changing urban geometry and anthropogenic heat is in the second plan. Communities can lower created anthropogenic heat by help of energy efficiency technologies in buildings and traffic, and renewable energy sources. Beside this, new researches show that waste heat has far greater impact on formation of UHI than was thought earlier – which is an additional stimulus to cut down anthropogenic heat sources. Solar cooling technologies and ground-air heat exchangers, which are described in the sequel of this paper, are the most promising technologies for lowering quantity of anthropogenic heat. On this way, at the same time, we contribute to energy independency of the cities, lowering electricity production in conventional power plants and decreasing human impact on environment. The benefits we get are multiple and diverse.

Beside anthropogenic heat we can make impact on other causes of creation of urban heat islands. By using functional water surfaces, e.g. solar pond for heat collecting or roof pond for cooling, we insure necessary water for evaporation and to some extent we change thermic characteristics of urban materials. With different shadowing solutions we are changing characteristics of urban geometry. Introducing changes in traffic (limited number of vehicles in city center, bicycles, pedestrian areas, electric vehicles, public transport) decrease quantity of waste heat but also air pollution. Methods for combating urban heat islands are listed concisely in Table II and Figure 2, where they are also connected with their emergence causes.

Table II Interdependency of urban heat islands and renewable energy sources

Causes	**Renewable energy sources**
Decreased amount of vegetation and impermeability of surfaces	Water surfaces: solar and roof pond
Changed radiation and thermal material properties	Water surfaces: solar and roof pond
Urban geometry	Shadowing (passive cooling)
Anthropogenic heat	Solar cooling technologies Ground-air heat exchanger RES in traffic Passive cooling
Air pollution	RES in traffic

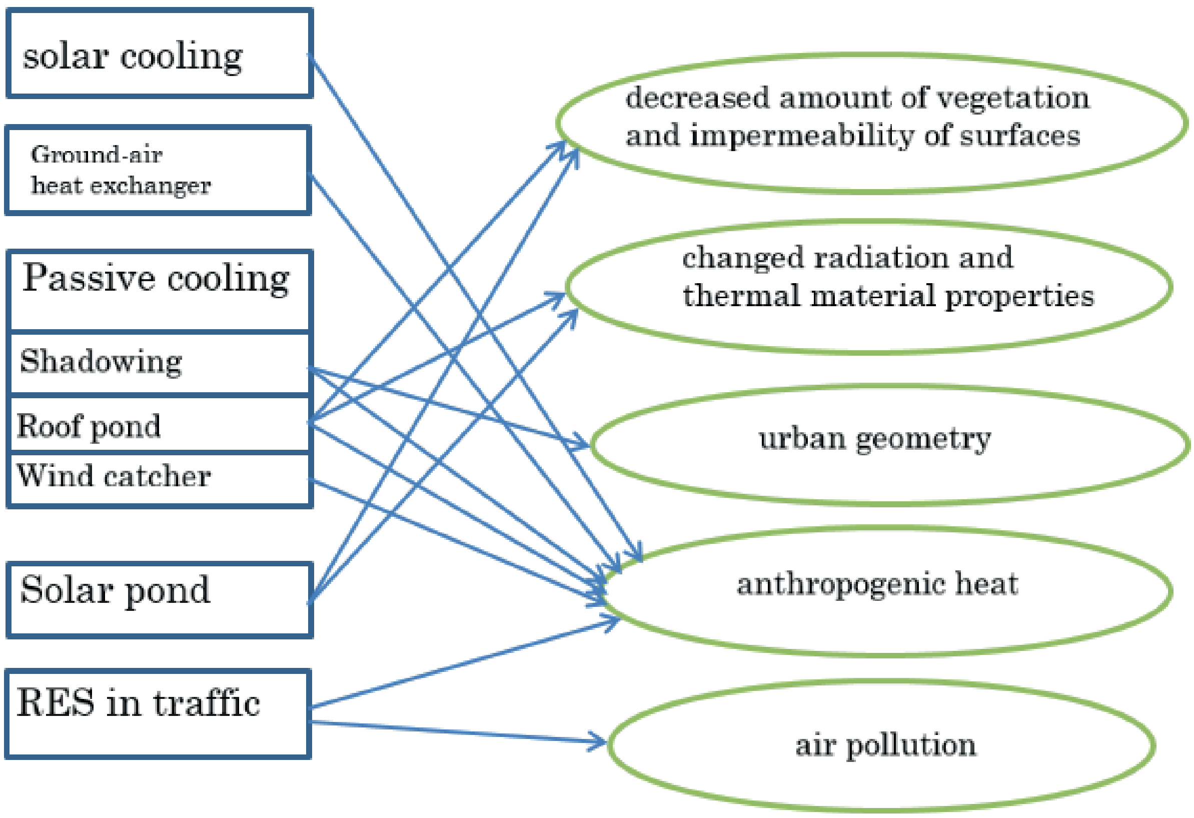

Figure 2 Interdependency of urban heat islands and renewable energy sources

4. ENERGY TECHNOLOGIES

4.1. Solar cooling

The main advantage of building acclimatization powered by sun energy is simultaneous availability of source (Sun) and cooling need in the same season (during summer), which is not the case for building heating. Solar cooling systems consist of two main parts: solar thermal technology for transformation of solar heat into hot water and solar cooling technology for production of cooling energy. Solar thermal technologies are the following:

- Flat collectors
- Vacuum pipe collectors
- Concentrating collectors (static and dynamic)
- Solar pond
- Photovoltaic panels

Solar cooling technologies are mainly classified into two main groups with respect to energy source: system initiated by heat or work and systems initiated by electricity. Systems initiated by heat or work are the following:

- Absorption cycle
- Adsorption cycle
- Cycle with dry evaporation
- Jet (ejector) cycle

Systems initiated by electricity are:

- Steam compression cycle
- Thermoelectric cooling cycle
- Stirling cooling cycle

The main problems of solar cooling in achieving economic competitiveness are high investing costs and system complexity. Therefore, this area of technical science is permeated with new solutions which tend at the same time to simplify and lower system costs.

4.2. Ground-air heat exchanger

A principle of using ground-air heat exchanger is based on the seasonal earth thermic capacity which causes time shift with respect to air temperatures. This temperature difference enables using earth for cooling during summer and for heating during winter. Ground-air heat exchanger is suitable for application in climates with high temperature differences between summer and winter, and between day and night, which corresponds to areas of moderate geographic latitudes and deserts. Simplified concept of such system is shown on Figure 3.

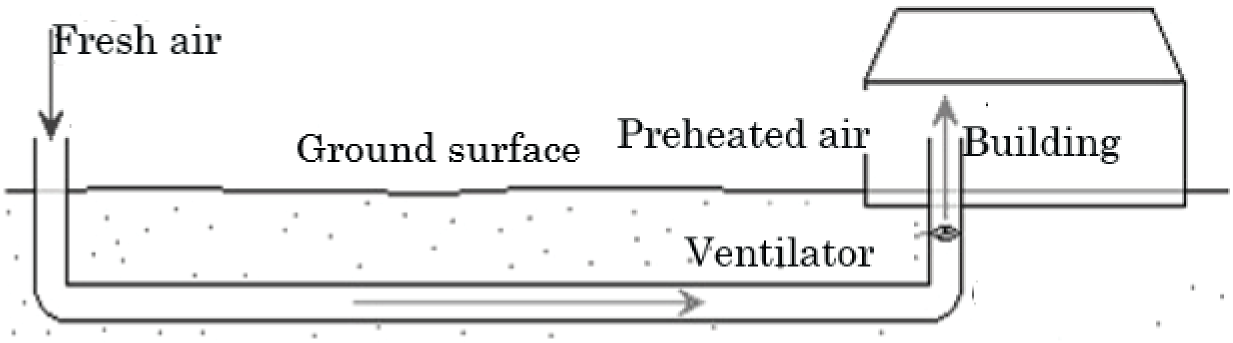

Figure 3 Simplified concept of ground-air heat exchanger

4.3. Passive cooling

Passive solar design incorporates application of natural processes for heating and cooling in order to achieve desired conditions inside the building. Energy flow in such buildings contain natural processes of heat exchange: radiation, conduction and convection without use of electric devices.

Prior to revolution of mechanic cooling machines in the middle of the last century, people were using different natural and clever methods for cooling (and for heating) of indoor spaces. Living spaces and also habits of their inhabitants, have been adjusted to outdoor conditions and to possible means of their cooling. "High technology" application resulted in negligence of natural cooling techniques. In the last few decades, in circumstance of fossil fuels exhaustion and ecological problems caused by their usage, we have become aware that is unreasonable to spend large amount of energy for cooling when our ancestors had managed to achieve thermal comfort by natural processes.

Maintaining comfort conditions inside the building, especially in the hot climates, is relied on decreasing heat incomes and removing heat excess from the building. Achieving above processes depends upon two conditions: cool tank availability which is on the lower temperature than inside air and possibility of heat transfer towards that tank. Tanks which are present in the nature are:

- Outdoor air (heat transfer by convection through openings in the building)
- Water (heat transfer by evaporation inside and/or outside of the building)
- (Night) sky (heat transfer by longwave radiation of roof and/or other building surfaces)
- Ground (heat transfer by conduction through building envelope)

The main techniques of passive cooling are [2]:

- Shading of sun radiation (eaves, awnings, different methods of roof shading, trees and vegetation)
- Isolation (walls and roof)
- Inducted ventilation technique (solar chimney, wind catcher, ventilation openings)
- Radiation cooling (metal roof, roof ponds)
- Evaporation cooling (water spraying inside wind catcher or on the roof)
- Connection to ground (digging in)

In the sequel are described two interesting ways of passive cooling: roof pond and wind catcher. A roof pond is a simple system of shallow water on the flat roof with good thermic conductivity and movable thermic isolation cover [2]. Pool is covered during the day in order to prevent heating of the water, while during the night is open and is cooling by longwave radiation. Covered pool during the day provides cooling thanks to effect of cooled water during the night and thermic isolation of the water on the other side. This system can be used for heating during the winter, but then isolation is moved during the day in order to heat water, while during the night pool is covered to prevent heat losses. On Figure 4 is shown working principle of roof pond.

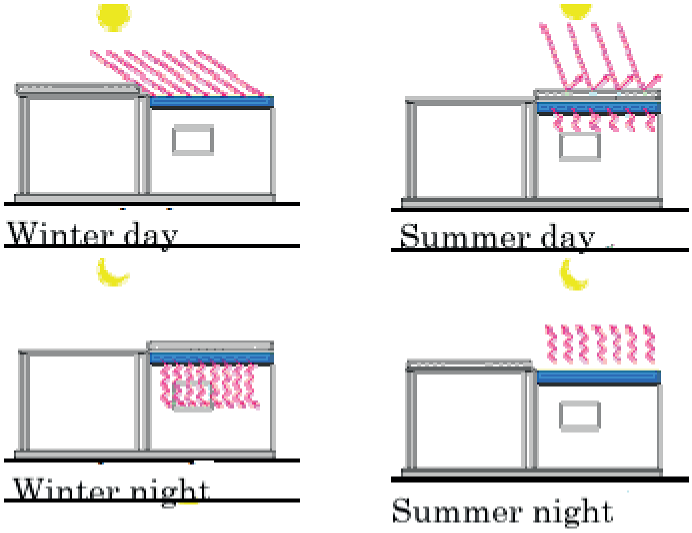

Figure 4 Roof pond operation principle

Wind catcher looks like a large chimney with openings on the top which lead wind into the inside of the building in order to enhance thermic comfort (Figure 5). Wind catchers had been using for centuries in countries with dry hot climate, especially in the Middle East where they are known under name “malqaf”. Opening on the top of the tower is oriented in the dominant wind direction in order to “catch” as much wind as possible during warm part of the year. In order to increase air humidity, inside the tower are placed water sprayers or inside pool or fountain.

Figure 5 Wind catcher in Iran [3]

4.4. Solar pond

Because of the positive role of the water on mitigating negative impact of urban heat island, solar pond is especially interesting technology for transformation of solar energy. A solar pond is a large surface sun collector which at the same time serves as an energy storage. There are several types of solar ponds: solar pond with salty water or gel, shallow ponds with cover, deep ponds with glass or plastic devices for retaining heat. The most frequently used are solar ponds with salty water and this type of pond is described in the remainder of this subsection. The main advantages of solar ponds are the following: simple construction, application of widely accessible salt and water, combined collecting and storing of sun energy. The key ingredient of solar pond with salt water, as its name say, is increased amount of salt dissolved in the water. There are three well defined zones or layers which can be seen on Figure 6: surface zone, gradient zone and storage zone. Salt concentration (salinity) and temperature are constant in the surface and storage layer, while in the transition layer are increasing with depth (Figure 7).

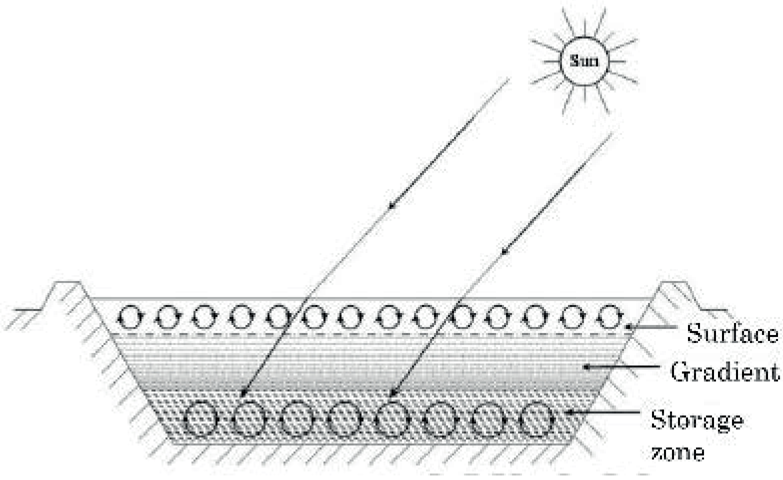

Figure 6 Solar pond system [3]

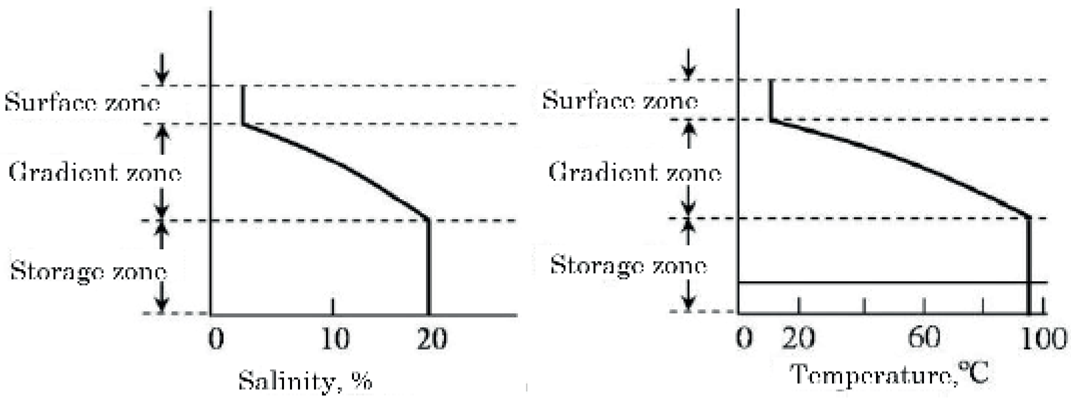

Figure 7. Salinity and temperature in the solar pond [3]

The most frequently used salts are magnesium chloride, sodium chloride and sodium nitrite. It is desirable that concentration in surface zone is low as possible (lower than 5%), while in the storage zone is from 20 to 30%. Typical depths of certain layers are 0.5, 1 and 1 m for surface, gradient and storage layer, and they vary with respect to specific application of the pool and meteorological conditions. Overall depth of such pools is in the range from 2 to 3 m. In periods with high sun radiation, water in the storage layer can reach temperatures around 80 to 90 °C. Increased temperatures with respect to surrounding can be kept overnight and to certain point even over the winter. Storage layer approximately absorbs 20-25% of incoming sun radiation that falls on pond surface. After considering ground losses, we come to the thermic efficiency between 15 and 20%.

Solar ponds generate thermal energy with lower costs with respect to burning of the fossil fuels. Solar ponds find their application in the conditions where water of low and medium temperature is necessary: heating and cooling of the buildings, heating of hothouses and farms, industrial process heat for preparing and treating materials, heat for biomass conversion, electricity production and desalinization. Especially is interesting application in combination with thermal cooling systems (absorption or adsorption) where warm water from the storage is used for generator operation and cool water from the surface layer is used for condenser cooling. Lack of this system is salt accumulation which decreases thermal efficiency.

4.5. Photovoltaic panels

Except electricity production, photovoltaic panels have positive impact on thermal characteristics of the building on which they are installed. Photovoltaic panels can be installed on several different ways: in immediate contact with roof surface, under certain incline or on the stands whereby they overshadow roof surface. If panels are installed under certain angle or on the stands, research has shown that this can significantly lower energy necessary for cooling inside the building [4]. Panels block direct sun radiation which directly decreases roof temperature and wind drift between panels and roof additionally increases the positive effect by convection cooling. At the same time, efficiency degree of the photovoltaic panels is increased because of their negative power-temperature coefficient.

Combine application of solar systems and cold reflecting roofs increases efficiency of solar systems thanks to better collection of diffuse and reflected sun radiation. Different institutions which have installed photovoltaic panels on cold reflecting roofs have reported photovoltaic electricity production 10 to 20% higher than expected [5].

5. CONCLUSION

This paper presents problematics related to urban heat islands: occurrence causes, consequences, conventional problem-solving methods and then tries to answer a question whether renewable energy sources and other energy technologies can contribute to reduction of negative impact of urban heat islands.

One of the conventional methods for mitigating UHI effect is broad use of water surfaces in towns: fountains, wells, artificial lakes. This way, necessary water is provided which by evaporation decreases air temperature. On the basis of investigated and described technologies, the main method which this research suggests is application of functional water surfaces, especially solar pond and then roof ponds. Solar pond collects and stores sun energy which can afterwards be used in different purposes.

Besides functional water surfaces, recommendation is combined application of other technologies: solar cooling systems, ground-air heat exchangers and passive cooling methods. For ventilator operation in ground-air heat exchange systems we can use for example small wind turbine. In order to improve image of the city as energy independent, sustainable entity, holistic approach is necessary. As air pollution also influence occurrence of urban heat islands, it is one more reason for transforming traffic patterns in cities, especially in their centers. In this area, renewable energy sources also play important role.

Besides well-known advantages of application of renewable energy sources, this research has additionally increased their cost-effectiveness, giving them one new dimension and specific benefit, which is rarely taken into account. Renewable energy sources can contribute to reduction of negative impact of urban heat islands.

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