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POLITECNICO DI MILANO

EARLY STAGE RESEARCH

COOLING CITIES
INNOVATIVE WATER-BASED COOLING SYSTEMS IN THE ERA OF URBAN HEAT

EXTENDED ABSTRACT

RESEARCH THROUGH DESIGN, URBAN HEAT ISLAND EFFECT, HUMAN THERMAL COMFORT, CLIMATE SENSITIVE, URBAN DESIGN, EVAPORATIVE COOLING

DDR STATEMENT

The study incorporates a design-driven research approach to develop innovative water-based cooling prototypes, able to intervene in the public space and respond to peek temperatures in summertime, improving the overall microclimate conditions of selected urban areas. The prototypes are designed and provided by the author. The chosen methodology entails using a mixed strategy to explore by quantitative methods the relation between the variables, and test them in two different scenarios, comparing and analysing the effects to human thermal comfort in a "before and after strategy". Meanwhile, the qualitative method implies organising a series of roundtables with experts to learn, analyse, evaluate and optimise the prototypes within a preestablished criteria for each roundtable (design, efficiency, costs, scalability). This process is considered a triangulation (validation) between relevant stakeholders, supported by a research through design methodology. Where each round serves as the starting point for the next round, and all the rounds constitute an iterative approach to maximise the prototypes overall feasibility. The different round tables consider at least one participant of the public and private sectors, academic institutions and international organisations. The importance of such an approach is to design, test and optimise innovative cooling prototypes based on experts knowledge and contributions.

ABSTRACT

The Climate Change phenomenon continues to affect urban areas and their populations. Some of the most pressing climate impacts are related to sea-level rise, changes in rain precipitation patterns (droughts and floods) and incremental heatwaves. The focus of this research is to understand the urban heat islands effect (UHI) causes, it´s characteristics and impacts on the health and the thermal comfort of citizens. The study analyses the state of art in urban cooling techniques, prioritising the use of water and evaporative cooling, but not limited to other passive techniques, design strategies and technologies to maximise the cooling effect at the local scale. The research uses a design-driven approach to develop innovative water-based cooling prototypes adequate to specific urban areas and microclimate conditions. Meanwhile, applying a research through design approach to optimise and document the results of each of the prototype´s performance in a series of iterative design-optimization process.

2nd Stage Submission

Revised Extended Abstract (1263 words)

Background, Context and Problem Statement

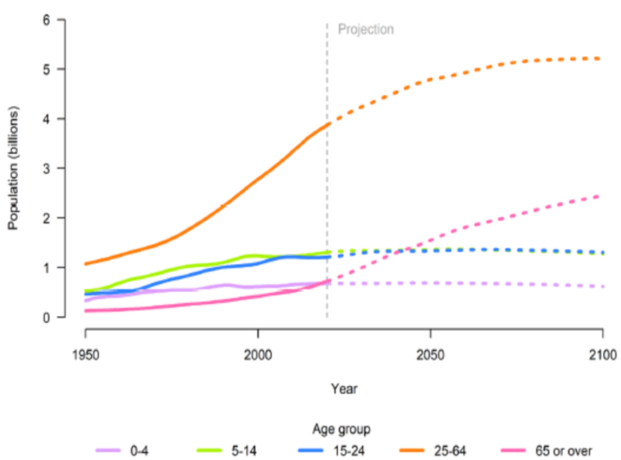
The so-called urban heat island (UHI) effect refers to the difference in temperature between surrounding rural and urban areas, mainly due to the absorption, creation, and retention of heat in the cities. It mainly occurs due to the substitution of the natural landscape with an urban layout (ex.-built assets such as buildings, streets and public areas) that usually retain heat during the day and release it back to the atmosphere above the city during night (8).

Climate Change affects human health, both directly and indirectly (4). The direct impacts have physical effects, such as exposure to high temperatures during heatwaves (dehydration, cardiovascular diseases, and heatstroke's) or diseases, injuries, and fatalities from extreme weather events (flash floods, droughts, heatwaves, wildfires). The indirect effects include changes to systems that support life, such as natural ecosystems and the services they provide to humanity (regulatory, provisory, supportive and cultural), or may also be a societal response to climate impacts, such as displacements of population and international migration.

The world has reached 7.7 billion inhabitants (2019), adding one billion people since 2007 and two billion since 1994. The prospects for the global population in 2030 are 8.5 billion and 9.7 billion by 2050 (medium-variant projections) (10).

In 2019, about 9% of the world population had 65 years or more. That percentage is expected to increase by 12% by 2030 and 16% by the year 2050. The projections entail that by 2050, people over 65 years (1.5 billion) will outnumber children and adolescents (1.3 billion), and they would be twice as many as children under five years. Meanwhile, the number of people over 80 years is growing even faster than those above 65 years. Between the years 1990 and 2019, this age group tripled to 143 million and will triple again to 426 million by 2050 (10). See Figure 1.

Figure 1. Estimated and projected world population by age group (UN medium-variant projection).



Source: United Nations Department of Economic and Social Affairs, Population Division (2019). UN, 2019.

Such a situation is concerning, considering the total amount of people in vulnerable situations from heatwaves exposure (like senior citizens and children) increased by 125 million from 2000 to 2016 (12). Europe has already experienced the catastrophic effects of heatwaves; in the summer of 2003, about 25,000 to 70,000 fatalities were heat-related (13).

More than half of the world's population is living in cities (55% in 2018), is estimated that by mid-century, two-thirds of the world's population would be residing in urban areas (68% by 2050). In contrast to the 70% living in rural settlements in 1950. In 2007, the global urban population exceeded the rural population for the first time.

Various factors impact city dwellers' thermal comfort; the morphology and climatic parameters of an urban area are among the most important (6; 7; 12). Urban morphology is mainly conformed by public spaces, buildings shape and scale, street geometry, vegetation cover, and the typology of materials used to build them. Such unique configurations are determinant to the city's microclimate, as it influences wind speeds and direction, solar reflectivity and absorption (albedo), shadow availability, global temperature, and the air relative humidity (8).

Research Topic

Research on cooling outdoor microclimates has gained much attention in the last decades due to the continuous increase in global temperature and the amount and increasing intensity of heatwaves striking cities worldwide (3).

Spatial planning principles and techniques are typically used for cooling outdoor urban environments. Some of the essential principles for cooling outdoor environments are ventilation, blocking solar radiation, improving albedo properties of materials, geothermal cooling, water evaporation and evapotranspiration from green areas.

Table 1. Urban Cooling Principles and Techniques Typically Described in Literature.

Authors	Oke (1978); Nikolopoulou (2004); Klok (2012); Santamouris (2015).	Taha, et al. (2002); Pomerantz et al. (2003); Santamouris, and Karlessi (2011); Santamouris (2012); Camielo et al. (2013).	Santamouris (2016).	Domínguez and Sánchez (2016); Nakayama and Fujita (2010); Steeneveld et al. (2014); Gunawardena et al. (2017)	Nakayama and Fujita (2010); Gunawardena et al. (2017); Ulpiani (2019).
Principles	Ventilation	Blocking Solar Radiation & Improving Albedo	Geothermal Cooling	Water Evaporation	Evapotranspiration
Techniques	Heat Dissipation; Design & Morphology of Urban Areas	Shadow Projection; Cool Materials, Pavements, Roofs and Facades	Geothermal Cooling	Evaporative Cooling	Urban Greening

Source: Author, 2020.

Many academics (5; 9; 1; 2) have established in their research that the presence of water in urban areas constitute a natural cooling technique, especially in hot/dry summer conditions. Their study reflects the relevance of water systems and their applicability to reduce air temperature due to the cooling potential of water evaporation.

Two main principles steer the cooling effect; the first is the evapotranspiration from vegetation; the second is the evaporation of exposed water sources. The absence of such principles in urban areas has been identified as the main reasons causing the UHI effect (6) and are directly related to urbanisation processes.

The fundaments of evaporative cooling rely on the evaporation of water. Some of the most important principles to consider for successfully using water evaporation as a cooling technique are within the principles of surface-area, volume-ratio and heat transfer from air to water or vice versa. Considering that water requires high amounts of energy to evaporate and that the highest the exposure of the surface area is, the higher the energy transfer due to evaporation may occur.

The energy necessary to evaporate water is taken from the surrounding air, which ideal conditions are dry/hot, resulting in an exchange of energy between them in the evaporation process (heat transfer), cooling the non-evaporated water and the surrounding air; as well as increasing the relative humidity. The total energy used to arrive at an evaporation point is known as latent heat (λ_{water}=2453 KJ/kg). The minimum reachable temperature output from this process is called the air wet-bulb temperature (1). Table 2 shows the common advantages and disadvantages of evaporative cooling.

Table 2. Advantages, Disadvantages and Limitations of Evaporative Cooling.

Advantages	Greatly reduces the air temperature (1kg of water = 2000m^3 of cooled air in 1°C)	Very low economical costs (natural process)	high thermal comfort and psychological perception	Supports multifunctional spaces, urban regeneration and climate resilience	Easy maintenance
Disadvantages & Limitations	Energy can only flow from a higher energy state to a lower energy state	When air reaches a humidity saturation point, evaporation processes are no longer possible	Cooled air needs confined spaces to avoid spread	Excessive use of freshwater or proliferation of harmful agents (ex: legionella)	Needs infrastructure changes (ex. pipes, water storage, etc)

Source: Author, 2020.

Architects and urban planners are more frequently including evaporative cooling in their spatial designs; what mainly hinders their comprehensive implementation is their reliance on specific microclimate conditions (relative humidity and global temperature) and their capacity to self-adjust to changes in the climate (11). For simplicity purposes, it is necessary to divide the water-based solutions into two categories.

The first category is horizontal elements, and they contemplate solutions on the ground floor designed in the form of water bodies, canals, ditches, water-mirrors, fountains and others. Meanwhile, vertical elements compose the second category and designed to function from a certain height. Indeed, it is easy to find many examples where both categories are combined to create a robust system. Table 2.2 shows the most common design categories in literature.

Table 2.2. Evaporative Cooling Principles & Techniques. Design Categories

Horizontal Elements	Water Bodies	Canals	Ditches	Water Mirrors	Fountains
Vertical Elements	Water Curtains	Water Nebulization	Downdraft Cooling		

Source: Author, 2020.

A well-known example of water-based cooling systems was showcased at the CIEMAT, EXPO 92-Seville. The exhibition focused on evaporative cooling techniques to refresh visitors under hot/dry summer conditions in Seville, Spain. One of the main cooling systems was developed by installing water spraying systems (nebulisers) in several towers of about 30m high, spraying micro-droplets of water to the air and inducing down-draft currents of cooled air.

Image 1. Application and Use of Water for Urban Cooling. Down Draft Cooling (modified by author).

Source: Expo Seville, 1992 and Santamouris, 2016.

Cooling Towers

Research Aim and Objectives

The research initiates by understanding the various causes originating the urban heat islands effect (UHI), it's characteristics and the impacts on human health and thermal comfort. Performing the "state of the art" in urban cooling techniques and principles, prioritising the use of water, but not limited to other passive principles, techniques, design strategies and technologies to maximise the cooling effect at the local scale.

The purpose of the research is to innovate in the field of climate-sensitive urban design, focusing on the use of evaporative cooling strategies and techniques to reduce the impacts caused by the "urban heat-island effect "on citizens health and thermal comfort.

Applying a research through design approach as methodology to design, test and optimise innovative cooling prototypes that reduce climate impacts on different urban areas and microclimates, analysing diverse parameters at the local scale. Focusing on enhancing the capacity of the selected areas to withstand the impacts related to heatwaves, and simultaneously to heavy precipitations according to the period of the year, working as a bridge to tackle the dichotomy between seasonal droughts and floods in localised urban areas, improving its overall resilience and the quality of life of citizens. Such an approach promotes further integration among resilient public space, urban design practices, academic research, and climate policies.

Image 2. Urban Cooling Principles and Techniques. Geothermal Cooling, Earth Pipes System and Niche for the Water-Based Cooling Prototype.

Earth Pipes System, Santamouris, 2016.

Geothermal (Water-Based) Cooling Prototype Niche, Author based on Santamouris original design, 2021.

Source: Santamouris, 2016; Author, 2021.

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