GREENING THE BUILDING ENVIRONMENT – CLIMATIC CHALLENGES, IMPACT, MITIGATION AND ADAPTATION SOLUTIONS


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Greening the Built Environment - Main Challenges of the Building Sector

**Global and Local Climate Change**
Increases the energy consumption, pollution, Health Problems, Decreases human productivity, increases costs

**Overpopulation**
Increases the need for additional housing and infrastructures

**Poverty**
A huge need to provide adequate and healthy housing, Indoor environmental quality and sufficient energy resources to billions of people

**Urbanisation**
Need for Sustainable Urban Planning and implementation of green technologies in the housing sector

**Provision of Sustainable Energy**
Need to provide affordable and sustainable Energy

**Economic Growth and Quality of Life**
Need to provide the proper space, housing quality, sustainable building regulations and development opportunities
According to the United Nations, the world population may increase up to 11 billion people by 2050, with most of the new population living in cities, increasing the urban population up to 6.5 billion people.
Urban Overheating is the most documented Problem of Climate Change

- **13,000 OVERHEATED CITIES**
- **1.7 BILLION PEOPLE UNDER SEVERE OVERHEATING**
- **THREE TIMES MORE OVERHEATING HOURS SINCE 1980**
- **118 BILLION OVERHEATING MAN HOURS**

Global Impact of Urban Overheating

Synergetic results between urban overheating, UHI, and heat waves cause a total urban stress higher than the sum of the background stress caused by the UHI and heat waves independently. Increased urban temperatures

**IMPACT OF URBAN OVERHEATING**

- Rise the cooling energy consumption in cities
- Decrease the efficiency of power plants,
- Increase the emission of pollutants,
- Rise the peak electricity demand,
- Intensify heat related mortality and morbidity,
- Lower the productivity of population and
- Affect the survivability of low-income households
Increases the Cooling Energy Consumption
Urban overheating is inducing an additional energy penalty at the city scale close to 0.74 kWh/m²°C, while the average energy penalty per person, is close to 237 (± 130) kWh/p

Decreases the Efficiency of Power Plants
A 1 °C rise of the ambient temperature reduces the power output of thermal and nuclear power stations by 0.6%

Increases the Peak Electricity Demand
The peak electricity rise per degree of temperature increase varies between 0.45% and 4.6%, corresponding to an additional electricity penalty close to 21 Watts (± 10.4) per degree of temperature increase and per person
Energy Impact of Urban Overheating - Cooling Degree Hours in Sydney

Impact Global Climate Change
+ 33 %

Reference 1990
820

Reference 2023
820

Moderate Urban Warming Zone 2023
820

Impact Moderate Urban Overheating
+ 81 %

Impact Strong Urban Overheating
+ 301 %

Strong Urban Warming Zone 2023
820

Impact Global Climate Change
+ 33 %

Reference 1990
820

Reference 2023
820

Moderate Urban Warming Zone 2023
820

Impact Moderate Urban Overheating
+ 81 %

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Strong Urban Warming Zone 2023
820
On August 2022, the UK Met Office recorded the country’s first-ever temperature above 40 degrees Celsius (104 degrees Fahrenheit) at London’s Heathrow Airport just before 1 p.m., as temperatures were still rising.

High demand sent power prices in the UK up 5% in one day. Across the Channel, things have been even more volatile. Europe’s heat wave has reduced France’s available nuclear power, as the river water used to cool nuclear plants became too hot to be effective.

As a result, day-ahead baseload power prices settled at 610 euros per megawatt-hour — about 10 times higher than prices from 2017 to 2021.
Overheating affects the urban environmental quality increasing the concentration of harmful pollutants.

Higher urban temperatures accelerate the formation of ozone precursors like VOC’s and NOx combining photochemically to generate ground level ozone.

Ozone is toxic and an oxidant affecting the human respiratory and cardiovascular systems.

The expected future increase of the ambient temperature is expected to further increase the concentration of the ground level ozone and the frequency of future severe ozone episodes, as well as the concentration of other pollutants.

It is estimated that the frequency of severe ozone episodes in four Canadian cities may increase up to 50 % by 2050 and 80 % by 2080.
Urban overheating obliges utilities to operate power plants for an extended period to satisfy the peak electricity demand.

Increased operation of thermal power plants significantly rises the emissions of pollutants and increases the concentration of secondary pollutants like the ground level ozone.

Each degree of temperature rise in the Eastern United States during the period between 2007-2012, resulted in a rise by 3.35%/°C ±0.50%/°C of the SO$_2$ emissions, 3.32%/°C ±0.36%/°C rise in CO$_2$ emissions, and a 3.60%/°C ±0.49%/°C increase in NO$_X$ emissions.

It is predicted that in 2050 the corresponding NO$_X$ emissions may increase by 16%, and the SO$_2$ emissions by 18%.

M. Santamouris, “Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability and health impact. Synergies with the global climate change,” Energy Build., vol. 207, 2020
Overheating affects the urban socioeconomic and biophysical vulnerability and has a serious impact on low-income population.

Vulnerable population lives in districts of disproportionately high UHI intensity, excess heat stress, higher risk of heat related mortality and significant socioeconomic vulnerability.

A significant correlation between exposure to extreme heat and the socioeconomic vulnerability exists for several cities resulting in almost twice the mortality risk in the deprived districts.

Vulnerable population lives in buildings of considerably lower thermal quality. Extreme indoor temperatures, 35-40°C, are recorded during extreme events in low-income houses.

Only 2% of the necessary cooling load is covered by low-income population in Portugal, while in Greece the cooling cost for low-income households is approximately double the average cost.

M. Santamouris and D. Kolokotsa, “On the impact of urban overheating and extreme climatic conditions on housing, energy, comfort and environmental quality of vulnerable population in Europe,” *Energy Build.*, 2015
Impact of Urban Overheating on Vulnerable Population

![Graphs showing CO2 Concentration over time and health threshold for Athens and Sydney.](image)
Impact of Urban Overheating on Vulnerable Population

A. Hsu et al.: Disproportionate Exposure to Urban Heat Island intensity across Major US cities. Nature Communications,
Heat related morbidity and mortality caused by the local climate change, is highly alarming, and it seems to be one of the current and future peak scientific topics. According to the existing epidemiological records almost 59,114 people passed away between 2000 and 2007 during 52 extreme heat events around the world.

Based on existing data collected from developed countries only, heat-related mortality may increase up to 30% in deprived areas of overheated cities.

In Europe, the number of people at high risk of mortality will triple at 3°C overheating compared to 1.5°C warming, in Central and Southern Europe and urban areas.

M. Santamouris, “Recent progress on urban overheating and heat island research. Integrated assessment of the energy, environmental, vulnerability and health impact. Synergies with the global climate change,” *Energy Build.*, vol. 207, 2020,
The monetized value of global heat-related mortality was estimated to be US$ 144 billion in 2021, equivalent to the average income of 12.4 million people.

In France Between 2015 and 2019, the economic impact of selected health effects of heat waves amounted to €25.5 billion.
Urban Overheating increases Mental Health Problems

Heat and Violence. Article in Current Directions in Psychological Science · February 2001
DOI: 10.1111/1467-8721.00109
Labour supply and human productivity may decrease up to 60% when ambient temperature exceeds 30-35°C.
Warming is expected to reshape the global economy by reducing average global incomes by roughly 23% by 2100 and widening global income inequality, relative to scenarios without overheating.

Economy in U.S. grows at a slower pace during hot summers. The annual growth falls 0.15 to 0.25 % for every 1 F increase of the average summer temperature.

United States could lose approximately $100 billion annually from heat-induced loss in labor productivity.

About 1 Million work life-years are projected to be lost by 2030 due to operational heat stroke fatalities with 70 million work life-years lost because of reduced labour productivity.

Simulated Increase of the Urban Temperature and UHI caused by the combined impact of greenhouse gas and urban expansion forcing, (RCP 8.5)

- Increase in the Surrounding Rural zone (2 x CO2)
- Increase in the City (2 x CO2)
- Increase in the City (2 x CO2)+ 20 W/m² anthropogenic heat
- Increase in the City (2 x CO2)+ 60 W/m² anthropogenic heat

Middle East (ME), Central Asia (CAs), West Africa (WAf), West North America (WNA), East Africa (EAf), South America (SAm), Europe (EU), Central America (CAM), East North America (ENA), Australia and New Zealand (ANZ)

Ref: Climate change in cities due to global warming and urban effects. Mark P. McCarthy, Martin J. Best, and Richard A. Betts, GEOPHYSICAL RESEARCH LETTERS, VOL. 37, L09705
We are able to build Zero Energy Buildings and Zero Energy Settlements.

However, the serious population increase, the tremendous increase of the penetration of A/C, the growth of floor area per person and the lack of technical knowledge and resources may result in a serious increase of the building energy consumption in the developing world.

There are almost 3.6 billion cooling devices in the world, increasing with a rate of ten devices per second. While in USA and Japan the penetration of air conditioners exceeds the 90% of the population, it is much lower in Southeast Asia, 15%, India and Africa, (5%).

It is estimated that only 10% of the 2.8 billion people living in the hottest parts of the planet have access to air conditioning.
200% and up to 2,000% by 2050, depending on the evolution of the main economic and climatic drivers.

Increased penetration of cooling devices, causes a very serious increase of the peak electricity demand, obliging utilities to build additional power plants that may operate for a limited time.

It is projected that the direct and indirect emissions from air conditioning and refrigeration devices may rise by 90% by 2050 above the 2017 levels.

By 2040, a nonnegligible fraction of the population will be left behind. On 2040, between 64 and 100 million households out of the total number of households living in the four countries considered in the latest waves of 343 million will face an adaptation cooling deficit.
Future Energy Consumption of Buildings – Penetration of A/C

Current and Future Cooling Energy Consumption in Emerging Economies per Income Group

- **BRAZIL**
  - Current and SSP5 Prediction

- **MEXICO**
  - Current and SSP5 Prediction

- **INDIA**
  - Current and SSP5 Prediction

- **INDONESIA**
  - Current and SSP5 Prediction

Expenditure Deciles

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<th>kWh</th>
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<td>10000</td>
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To counterbalance the impact of urban overheating, heat mitigation techniques are developed, and successfully implemented.

Mitigation technologies involve the use of advanced urban materials, like reflective, thermochromic, photonic, plasmonic and fluorescent materials, the increase of the urban green infrastructure, the use of evaporative systems, dissipation of the excess urban heat to low temperature heat sinks, or a combination of the previous technologies.
The recent development of Super Cool Materials like the photonic and fluorescent materials, permits decrease of the surface temperature of buildings and urban structures up to 15 C below the ambient temperature under the summer sun.
Mitigation: Photonic Day Time Radiative Materials Exhibit up to 10°C Sub Ambient Temperature under the Sun

Sample No.14
silica TPX sample 6+ESR2+ silver pet film
(with PE cover)

Air temperature (°C)
sample 6+Ag sample 6+ESR ESR

10:06am 22 Oct 2020 - 7:42am 28 Oct 2020
Air temperature(°C) Sample Surface Temperature (°C)
Mitigation: Colored Photonic Day Time Radiative Materials exhibit 4°C lower Temperature than White Paints Under the Sun


Average Day Time Temperature: White Paint: 24.6°C - Orange Fluorescent: 24.1°C - Average ΔT = -0.36°C - Max DT: 3°C

Surface Temperature (°C)

Surface Temperature Difference (°C)

AVERAGE DAY TIME TEMPERATURE: WHITE PAINT: 24.6°C - ORANGE FLUORESCENT: 24.1°C - AVERAGE ΔT = -0.36°C - MAX DT: 3°C
Performance data from numerous urban mitigation projects show an average reduction of the peak ambient temperature up to 3°C. The recent development of innovative mitigation technologies is expected to increase the mitigation potential up to 4.5°C.

Implementation of urban mitigation technologies can decrease substantially the cooling energy consumption, the peak electricity demand and the heat related mortality and morbidity.
Mitigation: We can decrease the peak temperature of cities up to 4.5°C and reduce the cooling energy consumption by 35% - Riyadh KSA.
Mitigation: We can decrease the peak temperature of cities up to 4.5°C and reduce the cooling energy consumption by 49% - Sydney, AU.
There currently is a shortfall of about 330 million homes in the world, and is expected to increase up to 440 million by 2025.

By 2030 the additional housing needs will grow by more than 77 billion square meters of floor space, equivalent or greater than the actual area of China.

We add a total floor area equal to the city of Paris per week.

More than 225 billion square meters of floor area will be built in emerging economies and mainly in India, Indonesia and Brazil.

Adaptation: How to Decrease the Cost of Decarbonisation and Promote Green Housing?

Temperature of Minimum Mortality in Europe

- Minimum Mortality at 17°C to 19°C
- Minimum Mortality at 25°C to 28°C

GDP/capita in PPP:
- 0 to 10,000
- 10,000 to 20,000
- 20,000 to 30,000
- 30,000 to 40,000
- 40,000 to 50,000
- 50,000 to 60,000

MMT (in °C [ATmean]):
- 16.0 to 17.5
- 17.5 to 19.0
- 19.0 to 20.5
- 20.5 to 22.0
- 22.0 to 23.5
- 23.5 to 25.0
- 25.0 to 26.5
- 26.5 to 28.0

Region:
- Eastern Europe
- Northern Europe
- Southern Europe
- Western Europe


The Human Thermoregulation System is not Responding to Heat the Same Way. Building Operational Standards must not be the same everywhere.
Adaptation: How to Decrease the Cost of Decarbonisation and Promote Green Housing?

Temperature of Minimum Mortality in China

The Human Thermoregulation System is not Responding to Heat the Same Way. Building Operational Standards must not be the same everywhere.

W. Ma et al: The Temperature – Mortality Relationship in China, Env Research 2015
Temperature of Comfort Sensation in Europe – Results of SCATS

Human Sensation of Thermal Comfort depends on the levels of thermal adaptation of the population. Building Operational Standards must not be the same everywhere.

Human Sensation of Thermal Comfort depends on the levels of thermal adaptation of the population. Building Operational Standards must not be the same everywhere.
Cooling Energy Reduction when Proper Set Points and Comfort Standards are Used

The use of proper Adaptive Comfort Standards considering the local adaptation levels can result in tremendous reductions of the cooling demand in buildings.

Reduction of the maximum indoor air temperature when cool roofs are used

Adaptation: How to Decrease the Cost of Decarbonisation and Promote Green Housing? Impact of Passive Cooling Technologies on Low Income Population
Reduction of the Cooling Demand and Thermal Satisfaction when Advanced Ceiling Fans are used

Adaptation: How to Decrease the Cost of Decarbonisation and Promote Green Housing? Impact of Passive Cooling Technologies on Low Income Population

Zero Energy Buildings in the Tropics – NUS SDE4 - Singapore

<table>
<thead>
<tr>
<th>NUS SDE4’s performance (April 2019 to March 2020)</th>
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<tbody>
<tr>
<td>Actual energy use during performance period</td>
</tr>
<tr>
<td>Actual energy produced during performance period</td>
</tr>
<tr>
<td>Net Energy Use</td>
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<tr>
<td>Energy Use Intensity (EUI)</td>
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</table>
Moving Towards a Gray Ecosystem in the Built Environment

**REFERENCE CONDITIONS**
- Low Energy Consumption
- Discomfort up to 30% of the year
- People mostly adapted to Current Temperatures

**INCREASE OF URBAN TEMP BY 3-4°C**
- Increase of the Energy Requirements up to 150%
- Discomfort up to 70% of the year
- People partly or non-adapted to High Temperatures
- Increase of Heat Related Mortality up to 40%
- Increase of Ground Level Ozone up to 70%

**AIR CONDITIONING TO SURVIVE**
- Increase of the Energy Consumption up to 400%
- Use of Cheap Low Efficiency A/C’s
- People living in A/C buildings adapted to low Indoor Temperatures
- Huge Increase of the Peak Electricity Demand – need for Huge new Infrastructures
- Heat from A/C increases the urban temp up to 2°C
- Low Survivability Levels of Low-Income Population
- Very Low Local Added Value.
Pathway towards a Green Urban and Building Ecosystem

Moving Towards a Green Ecosystem in the Built Environment

REFERENCE CONDITIONS
- Low Energy Consumption
- Discomfort up to 30% of the year
- People mostly adapted to Current Temperatures

MITIGATION OF OVERHEATING
- Decrease of Peak Ambient Temperature up to 4°C
- Energy Requirements remains constant
- Discomfort up to 20% of the year
- People fully adapted to urban climatic conditions
- Decrease of the Heat Related mortality up to 30%
- Decrease of the Ground Level Ozone up to 20%
- High Local Added Value

ADAPTATION OF BUILDINGS
- Increase of the Energy Efficiency up to 75%
- Increase of the Energy Consumption up to 50% because of the rebound effect and the partial use of A/C
- Low to Medium Increase of the Peak Electricity Demand
- Moderate need for new Infrastructures
- Further decrease of the Heat Related Mortality
- Better Survivability Levels for Low-Income Population
- High Local Added Value
Estimated Cost to Mitigate Urban Heat and Decarbonize the Built Environment

The total cost of urban overheating is estimated between 500 – 700 billion US $ per year, and may increase up to 1.3 Trillion US $ by 2050.

Annual Cost of Decarbonisation of Buildings

Source: Mc Kinsey Analysis

Annual Cost Mitigation Urban Heat

Source: Personal Calculations and Data

95 – 350 Billions

1.6 Trillion $ US
Urban Warming Markets

Helping Counterbalance Urban Overheating

Setting as a goal a minimum urban overheating and pollution involves limiting the strength of warming and polluting sources and increasing the strength of urban heat sinks to balance the urban heat budget.

Achieving a Zero Urban Thermal and Pollution budget requires to:

- Change the way we design, built and operate urban buildings, spaces and infrastructures and transition to less warming and polluting patterns and policies.

- Put a value on the urban mitigation and adaptation capital that limits the strength of local climate change and environmental quality.
Towards Urban Climate Change Transition – A Mandatory Urban Warming Pricing and Credit Mechanism

Putting a Price on Urban Warming

The magnitude of overheating and pollution caused by selected major urban activities has to be assessed and controlled. Liable entities exceeding the threshold and causing urban warming must pay a price for every warming or pollution unit, shortfall cost, or either to surrender the appropriate number of allocated units.
Boosting Sustainable Urban Investments

To accelerate urban cooling and finance urban heat mitigation and adaptation it is critical to value urban overheating with liquidity. The development of a voluntary Urban Warming Market could bring urban mitigation and adaptation investments sooner to the market and make them more affordable. The scheme will bring new sustainable urban business, will boost profits and will skyrocket the investment of new green capitals in cities.
Strong Synergies between the Sectors Affecting Urban Climate Change

The serious heterogeneity of the quantitative and qualitative conclusions drawn by the existing studies can be mainly attributed to the differentiation of the synergetic association of energy, pollution, health and vulnerability in the considered cases.

The need to adopt a more extended and interdisciplinary frame for impact studies considering all possible synergies is quite evident.

Studies on the impact of overheating on energy, pollution, vulnerability and health, provide knowledge on the specific impact on energy consumption, peak electricity, efficiency of the power plants, concentration of ozone, emission of power plants, vulnerability and health.

While the provided information is rich in quantified data, it is highly fragmented and fails to consider the problem of the overheating impact in an integrated and holistic way.
Investing and Counterbalancing the Urban Climate Change is the Next Productivity Engine to Drive Growth