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Article

The Mitigative Potential of Urban Environments and Their Microclimates

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Abstract: Cities play a crucial role in climate change: More than 50% of the growing population lives in cities producing most of the global GDP but also 78% of greenhouse gases (GHG) responsible for climate change. Moreover, due to their highly modified land-use and intensive activities, cities are at the forefront of the most rapid environmental and climatic change ever experienced by mankind. Yet, cities' potential to mitigate both climate change and their own environment is underexploited. This paper explores ideas related to the potential of urban environments to modify their microclimates, reflecting on the overlapping potential between mitigative and adaptive actions. These actions in cities can not only tackle some of the largest contributing factors to global climate change but offer short- to medium-term benefits that could drive more immediate socioeconomic and behavioral changes. This review proposes and discusses a new preliminary definition of urban environments as microclimate modifiers—Mitigative urban Environments and Microclimates (MitEM)—and calls for further research into: (a) inter-connecting the full range of mitigative and adaptive initiatives already being undertaken in many cities and maximizing their input systemically; (b) developing a common and holistic definition of MitEM; (c) promoting its uptake at policy level and amongst the key stakeholders, based on its social and public value beyond the environmental.

Keywords: mitigation; passive buildings; urban environments; human behavior; mitigative urban environments; urban heat island

1. Introduction

Economic activities of cities account for the largest part of the world's economy as 150 of the world's most significant metropolitan economies produce 46% of the global Gross Domestic Product [1]. As of 2007, more than 50% of the global population is urbanized and it is estimated that cities, while covering only around 2% of the earth's surface [2], are now responsible for 71%–76% of CO_2 emissions from global final energy use and between 67% and 76% of global energy use [3].

Greenhouse gas (GHG) emissions have been identified as a main contributor to climate change (CC). In the future it could manifest in different ways but there is agreement on the warming trend and the increased frequency of extreme weather events [3]. Within this scenario cities themselves are experiencing changes in microclimatic condition, caused by the dense urban processes and built environment, which are independent from and much greater than CC itself and that tend to amplify its effect, posing urgent societal and economic challenges that need to be faced in the short to medium term. In fact, the great modification of urban microclimates will in every case impact on the future development of cities.

Future projections of global urban population estimate further growth, with 64%–69% living in cities by 2050 [3]. This will put even more pressure on current urban environments and infrastructures and will create a greater demand for space and energy. Yet, the ability of cities to mitigate and adapt to CC by reducing their GHG emissions and improving their urban environments and microclimates is underexploited and this is represented by fragmented and sectorial technical strategies and policies concerning CC.

Previous studies have looked at the urban contribution and microclimatic dimension of buildings, implicitly recognizing the "mitigative" potential of the built environment [4] and the necessity of a more sophisticated definition of building, which identifies its potentially positive contribution to the physical, biological, and ecological environments [5]. Other studies on Zero Impact Buildings [6] and 0-Impact Built Environment [7] have touched upon the concept of a closed resource cycle for buildings and have reviewed various definitions with the aim of proposing a new common one towards a paradigm shift in the building sector. However, in both cases these studies measure the impact of the built environment, emphasizing its relationship with energy sources and other resources such as land use and water, and do not explicitly consider the impact of buildings on the environmental performance of their surroundings.

This paper aims at reviewing the current state of the art on urban environmental problems in the context of climate change and the possible associated mitigative and adaptive actions. The review identifies new areas of research and application, suggesting a future paradigmatic shift in policies and practice aimed not just at minimizing the negative impact of cities but also creating built environments that make a positive contribution to the physical, social, and microclimatic urban environment.

2. Mitigation and Adaptation: A Problem of Definitions, a Point of Convergence

Mitigation and adaptation are often referred to in the language and terminology surrounding climate change studies and are used in a variety of disciplinary contexts [8]. The Intergovernmental Panel on Climate Change first defined mitigation and adaptation in its fourth assessment report, distinguishing clearly between the two [9]. Mitigation is defined as an "*anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases*", whereas adaptation is defined as an "*adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate harm or exploit beneficial opportunities*". Since then the relationship between mitigation and adaptation has been much debated and commonly the former refers to proactive long-term actions that primarily aim at reducing GHG emissions on a large scale (national and international), whereas the latter refers to reactive short- to medium-term actions that aim at increasing the resilience of local communities and their physical environment to withstand the local consequences of climate change.

However, local consequences are far more tangible and perceptible than global climate change [2]. Cities, in fact, are experiencing changes in microclimatic conditions that are much greater than the CC itself [2] and that must be attenuated in the short to medium term. Applying literally and traditionally the dichotomy mitigation/adaptation, the attenuation of urban microclimatic conditions and the reduction of the Urban Heat Island (UHI) could fall into the adaptive measures group. However, some adaptive measures are intrinsically also mitigative as they reduce not only the effect but the cause of the local and global climatic changes.

It has been noted that the traditional division between the two actions is now outdated since appropriate and focused actions are able to simultaneously promote mitigation and adaptation [10]. This intersection between mitigation and adaptation has been also referred to by others [8] as the "mitigation–adaptation lens" through which the existing action frameworks should be able to identify synergic opportunities for both dimensions. For the scope of this proposal there is an interesting parallelism between the potential "mitigative" properties (mitigative as moderating and tempering from the Latin root *mitem*) of the urban microclimatic environments and their CC "mitig-adaptive" potential, as we could call it.

In fact, the same strategies proposed for the improvement of urban environments to mitigate their microclimates can simultaneously assure a short-term adaptation of the urban environment to the effects of local and global CC and a radical and sustained mitigation of the causes of CC (Figure 1).

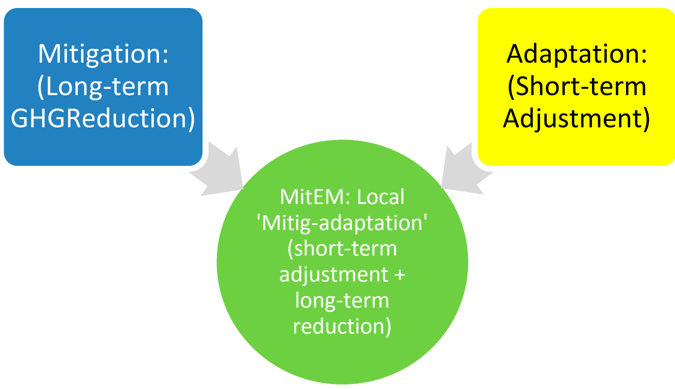

Figure 1. Proposed approach as intersection between mitigation and adaptation.

3. The Situation Today: The Current Urban "Landscape"

Due to their economic and polluting role, cities will play a fundamental role in the sustainable development of global economy and in the effectiveness of CC actions. Throughout history cities have been, and still are, the economic, social, and cultural engines of our world [11]. However, these engines are still polluting, being responsible for 78% of GHG emissions. Due to highly modified land-use and concentrated urban activities, living in a large city today is like living, without realizing it, on the edge of the most rapidly changing environmental conditions ever experienced by humans [2]. The complex phenomena characterizing urban environments and microclimates have been studied as part of the Urban Heat Island (UHI) effect [12]. This relates to the relative higher warming of the cities' cores as compared to the rural surroundings and to the warming of the global climate. Average maximum summer urban heat island intensities in city streets can range from 3.5 to 7 K higher than the surrounding countryside, while the annual average temperatures differences were between 1 to 3 K [13]; this will also exaggerate the impact of changes in weather patterns due to CC as in the case of vulnerable regions of the world such as Ho Chi Minh City in Vietnam [14].

Urban Heat Island has a serious impact on the energy consumption of buildings, especially during the cooling period, while it worsens the environmental quality of urban areas as well as the thermal comfort of their inhabitants [15]. This in turn affects the image of a city [16] and leads to spaces characterized by discomfort to be avoided or poorly exploited [16]. Below follows a review of the current issues and shortfalls around urban environments and their microclimate in an attempt to propose innovative viewpoints and potential interdisciplinary synergies for future research.

3.1. Urban Microclimate: The "Street Section" and the "Negative Loop"

The microclimatic modifications in the urban environment are produced by the interaction of the causes of CC with specific urban issues such as alteration of the surface energy balance (*i.e.*, higher albedo, reduced evapotranspiration potential, and increased thermal storage), waste-heat and localized generation of pollution, human behavior, and other factors. It has been observed [17] that the factors contributing to climate change have often been driven by powerful commercial stakeholders, including the energy, construction, and banking industries, which address cities as agglomerations of assets rather than "living organisms".

As a consequence, urban environmental and microclimatic issues are particularly complex—as their causes and effects are interrelated. The physical and metaphorical backdrop of this interrelation is what we call the "*street section*", where the "*negative loop*" takes place (Figure 2). A definition of both follows.

The importance of the "*street section*"—which comprises the streets, the public space between buildings, and the outer boundary of buildings—can be explained along three dimensions:

- The "*street section*" offers a microsystem approach, which is particularly relevant to the environmental sustainability of microclimatic challenges. It exemplifies the "*negative loop*" of causes and effects of the urban microclimatic changes and of environmental pollution in their intercorrelation. For instance, mechanical systems for cooling are excessively used due to overheating of the "*street section*" in summer but they also further contribute to an increase of the outdoor temperature due to waste heat from compressors. This creates a vicious circle augmented by the lack of awareness amongst inhabitants of the environmental damage of such systems. In order to reduce their use both in terms of people's behavior and provision of alternative cooling strategies, pollution and heat must be reduced and people's awareness increased. However, to reduce pollution and avoid the use of mechanical cooling, air quality for natural ventilation must be improved and alternative forms of mobility must be enhanced by offering better opportunities and conditions for the uptake of alternative transportation modes (e.g., walking, cycling, and low-emission public transport).

- It represents the responsibility and the remit of the stakeholders involved in the "*street section*"—e.g., tenants, transport authorities, urban planners, local authorities, companies, industry, and SMEs, and their attitude towards, for example, private mobility and indoor comfort.
- It offers a key interface between the above and the other dimensions of sustainability—social and economic as promoted through the UN "prosperous streets" approach (see following sections). It then underlines the need for a multidisciplinary approach that involves technical—such as transport, urban planning, and built environment specialisms—and socioeconomic disciplines with the active engagements of the different stakeholders of the "*street section*", since responsibilities and solutions are scattered at all levels of public and private engagement.

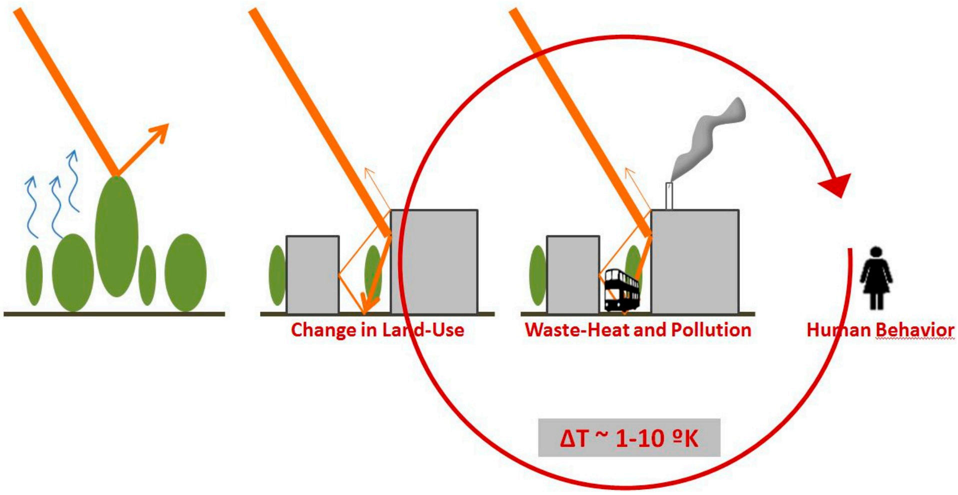

Figure 2. The negative loop and factors contributing to the deterioration of the street section.

3.2. Direct and Indirect Costs and Consequences of the "Negative Loop"

The causes and effects identified in the "*negative loop*" of current urban environments have a number of direct and indirect costs and consequences for local authorities, urban inhabitants, and global CC.

The "*negative loop*" impoverishes the quality of the "*street section*" and the urban microclimate, causing detachment and isolation from the outdoors and consequently an extensive use of mechanical systems to achieve indoor comfort when it is not required. It also reduces the use and enjoyment of open spaces that are extremely relevant for urban prosperity and economic growth in developed and developing countries alike [16].

In general, high urban temperatures have a serious impact on the quality of life of urban citizens and affect the local economy. In fact, it increases the energy needs of building for cooling purposes, affects the health of the urban population, raises the concentration of specific urban pollutants, increases the ecological footprint of cities, and deteriorates outdoor and indoor thermal comfort levels while it augments the risk to the vulnerable urban population during periods of extreme heat [15,16,18,19].

In energy terms, this is particularly crucial in summer when, in many climatic regions, bioclimatic strategies—e.g., natural ventilation and passive cooling—could avoid or reduce the use of mechanical systems. However, this could also occur in winter, when—paradoxically—mechanical systems for cooling are used in those spaces with high internal heat gains such as offices and commercial spaces, even at high latitudes.

Studies have quantified the increase in energy demand for comfort due to microclimatic changes in summer: in particular, analysis of several studies has shown that increased urban temperatures raise the peak electricity demand and oblige utility companies to build additional power plants. It is estimated that the corresponding increase of the peak electricity demand per degree of temperature rise varies from 0.45% to 4.6%, while the energy penalty per person is estimated at close to 21 W per degree of temperature rise [3,18,20]. In parallel, the additional electricity consumption per degree of temperature may vary between 0.5% and 8.5% [20].

In parallel, estimations regarding the additional energy consumption of urban heat island for cooling purposes indicate that the Global Energy Penalty per unit of city Surface (GEPS) varies between 1.1 and 5.5 kWh/m^2, while the Global Energy Penalty per Person (GEPP) varies between 104 and 405 kWh/p [10]. Finally, a synthesis of many energy studies performed around the world has concluded that for the period from 1970 to 2010, the average increase of the cooling load of reference buildings is around 23%, while the corresponding decrease of the heating load is found to be close to 11% [21]. As a consequence, the environmental as well the economic penalty of this increase is relevant especially if considering the economic loss caused by the blackouts due to the extensive use of A/C during heat waves [2].

Worldwide, there is a greater percentage of highly populated cities in hot-climate regions than cold-climate ones. If global warming and urban microclimatic changes—are added on top of the standard climatic regions, globally, in cities, there is a shift towards hot conditions and consequently a greater demand of energy for cooling than for heating. This means that the wasted energy for comfort in cities caused by the urban microclimatic modification is substantial. At the same time, it could be said that the energy saving potential due to the improvement in the urban microclimate is also considerable.

Other consequences relate to indoor and outdoor discomfort, reduced productivity, health and excess deaths, quality of life, and biodiversity. Existing medical research has shown that during the period of heat waves the number of admissions in hospitals increases significantly [22]. As reported in Melbourne, Australia, hospital admissions increase by 37.7% when the average temperature during two consecutive days is higher than 27 °C [22]. At the same time, human mortality presents a strong correlation with ambient temperature. Studies from a number of European cities have shown that mortality increases rapidly at threshold temperatures above 29.4 °C in Mediterranean cities, and above 23.3 °C in Northern and Continental European cities [23].

Moreover, microclimatic changes of large urban environments modify the pattern of the local weather. As the urban microclimate amplifies the magnitude of heat waves making cities and their inhabitants more vulnerable, it can also intensify other weather events such as precipitation patterns.

Rainfall in Ho Chi Minh City, one of the most flood-prone cities in the world, has been on a steady upward trend for over a decade and this has been attributed to urban microclimatic changes rather than CC itself [14]. The energy demand increase, health issues, death risks, and other consequences can potentially be much higher for low income and more vulnerable groups of society due to the poorer condition of their housing, the lower affordability of high efficiency goods, and the usually denser and overheated zones of cities where they live—further emphasizing social disparities and energy poverty. The urban heat island highly affects indoor comfort conditions in low-income housing. Studies performed in different parts of the world have shown indoor comfort conditions during heat waves exceeded highly the set threshold limits for health and wellbeing [24–26]. It is characteristic that maximum indoor temperatures in low-income houses in Athens, Greece during the 2007 heat wave have reached 45 °C, while long spells with indoor temperatures above 30 °C are recorded [25].

Clearly the increase in urban ambient temperature during the summer has a negative effect on outdoor thermal comfort conditions. Several studies have shown that there is a significant spatial and temporal deterioration of the outdoor thermal comfort conditions and consequently of the attractiveness of open spaces impacting the local economy [16,27]. Studies in Athens, Greece have shown that the frequency of uncomfortable days doubled between 1954 and 2012 [28], while the calculation of the spatial distribution of the humidity index in the city showed that dangerous and uncomfortable conditions occur in July and August in the western parts of the city for a significant period of time [29].

3.3. Gaps in Policies, Cross-Disciplinary Considerations, and Private–Public Involvement

The reasons for many cities' inability to improve their microclimate and deal with CC and with the risks of extreme weather events are several. Primarily they are associated with: lack of public awareness about the impact of local and global CC; lack of consistent urban policies and systemic action plans; and a lack of capacity to appeal to externally allocated resources [30].

International, national, and urban policies are mainly focusing on energy efficiency in a number of ways, especially for new buildings, energy supply, and products in order to reduce CO_2 emissions. However, while the building scale policies have imposed minimum thermal conditions for building elements, a large proportion of their energy performance will be influenced by and influencing the urban environment, for which no policies exist [31]. Efficiency is a milestone against CO_2 emissions but it is not sufficient to tackle urban issues and eradicate the causes and effects of the "*negative loop*" that are happening at the "*street section*" level and, as will be explained later, it is often not a feasible pathway for emerging and especially developing countries. Moreover, studies have shown how the reduction of GHG emission in cities, though fundamental for the quality of the urban environment, will not yield significant reduction in urban temperatures since its increase is mainly caused by land use modification and waste heat.

The policy gap that has been highlighted above is one of the main barriers to be addressed (Figure 3). In fact thinking of the different components of a city—*i.e.*, transportation, buildings, streets, and parks—as disjoined elements is a limit for their sustainable development. Studies found that cities with an extensive portfolio of low-carbon urban innovation projects did not achieve the expected impact because their projects were usually treated separately from each other in a stand-alone project management fashion, which reduced their transformative capacity [30].

Figure 3. (**left**) Isolated system: the figure represents the aim/scope of traditional focus on energy efficiency; (**right**) The gap.

4. Pathway towards MitEM

This gap in policies between the building and the urban scale is mirrored by a lack of recognition of the strategic importance of the "*street section*" design as a microclimate modifier in itself, and hence of its mitigative potential. The main instruments towards implementation of urban microclimatic mitigation strategies are currently found in fragmented technical solutions and sectorial policies that fail to identify the multiple relationships of cause and effect that lie in the various elements of anthropogenic activities. They also fail to actively involve the relevant stakeholder network necessary to define potential city-wide transition pathways, which are key to effective mitigation actions.

These actions can be found, for example, in the provisions of green areas, roofs, facades, or infrastructural improvements, which mitigate the urban microclimate and reduce the urban heat island. Hence the dual "mitig-adaptive" effect: by reducing the UHI magnitude, the need for active systems will be reduced and energy and CO_2 emissions will be saved. In turn this will reduce the impact of always more frequent heat waves or other extreme weather events, such as heavy rainfall, increasing the water retained locally and hence reducing the risk of floods. As exemplified by the "*negative loop*" of the "*street section*" introduced earlier, all these elements are interrelated and equally crucial and therefore must be improved harmoniously. Hence the gap between urban and building scale intervention must be covered, especially because buildings have a large impact on the microclimate of cities and it is not sufficient to improve their indoor performance to make the shift towards more resilient cities. Their impact on the outdoor microclimate must be acknowledged and addressed urgently.

In order to enable our cities not just to minimize their impact but to create built spaces that make a positive contribution to the physical, social, and microclimatic urban environment, a holistic approach is needed (Figure 4). Technical strategies to mitigate the urban microclimate are well known in literature and practice and they range from efficient transport, cool surfaces, green roofs, open spaces, water bodies, and a reduced thermal mass in the street section to enhanced ventilation. Moreover, their individual benefits have been tested and quantified. Among them, the use of reflective materials to be applied on the urban buildings' fabric, the use of additional green spaces and green roofs in cities, the use of the ground for heat dissipation and other techniques associated with the use of ambient sinks, seem to be the most developed and technologically advanced [32].

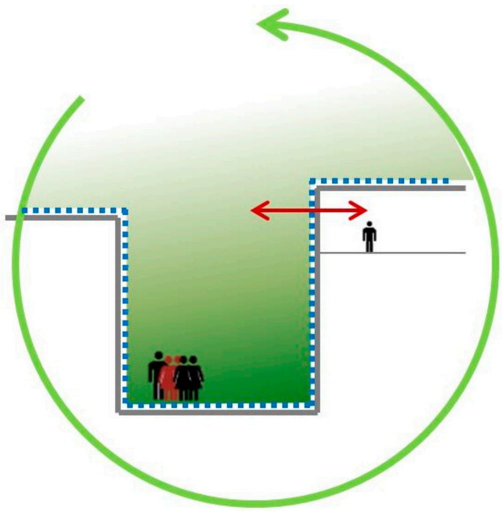

Figure 4. The positive loop.

Reflective or cool materials present high reflectivity in the solar spectrum together with a high emissivity factor [18,33]. The use of cool materials on the roof of the buildings may decrease the corresponding surface temperature by several degrees and highly contribute to decrease their cooling needs. Thousands of applications are already performed around the world with significant energy and environmental benefits [2,34,35]. In most of the cases the surface temperature is reduced by 10–15 K and the cooling load by 20%–30%, depending on the characteristics of the building. In parallel, cool reflective materials are used for urban pavements in order to decrease the surface temperature of the urban fabric [28]. Hundreds of applications involving cool paving materials have been realized and monitored. Results show that it is possible to reduce the peak and average summertime temperature of open spaces by several degrees and also improve the global environmental quality of the cities [2,18,36].

Increasing the green spaces in a city highly contributes to decreasing its ambient temperature. Urban green spaces cool cities through evapotranspiration and solar control and is associated with the development of cool islands in and around parks and public green spaces [2,18,37,38]. Cool islands created by urban parks offer improved comfort conditions and lower ambient temperatures around them and to a distance equal to their length. Appropriate spatial distribution of parks and other open green spaces can significantly decrease the average surface and ambient air temperature of cities. However, the lack of available open spaces in cities significantly reduces the potential for further integration of urban parks. The use of green or planted roofs seems to be a very powerful climatic solution. Planted roofs decrease the surface temperature of the buildings and decrease the temperature of the air above them using latent heat processes. Their mitigation potential depends on their characteristics and the local climatic conditions, but they may offer more than 150 W/m^2 during the peak cooling period [39]. As for the cool reflective materials, the benefit of the vegetation on sun-exposed facades contributes to reducing the energy demand of buildings while significantly reducing ambient temperature; consequently, thermal comfort may improve considerably [40].

The use of heat sinks that present a lower temperature than that of cities, presents high potential for dissipation of the excess urban heat [41]. In particular, the implementation of earth to air heat exchangers to provide cool air in open urban areas has recently gained significant interest. Buried pipes may decrease the temperature of the air flowing through them by up to 10 K and thus provide comfort around them. Evaporative techniques like permeable pavements and sprays are also tested and employed in urban areas where excess of humidity is not a major problem.

Other interesting studies and practices involve the efficiency of public transport in cities and the classification of streets with different priorities. For example, the Road Task Force in London is setting up strategies to redefine streets according to their effective use, allowing heavier traffic to be diverted to specific boulevards while leaving local streets for uses different from mobility [42]. These strategies will reduce not only pollution but also noise and waste heat, especially at a local level. Analyses have demonstrated the importance of reducing the waste heat from cars in cities and quantified its benefits as 2–4 °F [2].

This paper identifies in the proposed approach a new and systemic area of application of all these single strategies, suggesting a future paradigmatic shift in policies and practice aimed not just at minimizing the impact of cities but also creating built spaces that make a positive contribution to the physical, social, and microclimatic urban environment.

The development of a new definition of Mitigative urban Environments and their Microclimates (MitEM) is needed to express the potential of the urban environment to moderate, make milder, temper (from the Latin "*mitem*"), and promote its uptake at policy level and amongst key stakeholders, based on its social and public value beyond the environmental. In fact, to take action on the urban environment in order to improve its microclimate, it is paramount to first recognize its role as a social good and integrate this recognition into the current discourse on public spaces and "prosperous streets" [43] as a driver for "urban prosperity" [44]. The recognition of social good comes from its ability to improve microclimates and, consequently: to reduce the energy demand and GHG emissions; to reduce the pressure of energy bills for comfort on urban inhabitants; to provide comfortable and healthy environments for indoor and outdoor related work, leisure and movement related activities; and to reduce the risks of and better adapt to extreme weather events in cities.

5. The Potential of MitEM

The level of technological readiness in strategies and techniques now available on the market to help improve urban microclimatic conditions and the level of advancement in performance analysis of outdoor spaces have made possible the design and delivery of MitEM. It has been noted that "*during the years the techniques used for these purposes (designing public livable spaces) improved, but only today do we have the sophisticated means for an optimized designing of outdoor spaces. In other words it can be possible to improve the quality of an outdoor public space by taking care of those factors influencing the thermo hygrometric comfort*" [16]. The potential for the implementation of the pathways towards MitEM, which expresses the ability of urban environment to mitigate their microclimate through the strategies mentioned above, will be: (a) to reduce building energy demand; (b) to change human behavior; (c) to make "Urban Prosperity" resilient to change; and (d) to offer parallel and low-tech pathways to efficiency focused actions.

5.1. MitEM and Energy Demand Reduction

Transport and buildings account for 65% of total urban GHG emissions. Moreover, the energy used by buildings for comfort today represents around 60% of their operational energy, whereas transport is responsible for around 20% of global GHG emissions [45]. Buildings consume so much energy for comfort partially because of the low levels of efficiency and poor quality of the existing building stock but also because of the untapped energy reduction potential of their urban microclimates (see "*negative loop*" above).

Supported by the output of previous European projects, such as the Altener Cluster 9 Project [46] and other FP7 projects [47], which identified the poor quality of urban environments and microclimates as one of the main barriers to the implementation of bioclimatic strategies (*i.e.*, passive solar strategies that are climate responsive and human centered) in cities, the current review calls for the development of systemic and comprehensive actions to allow the applicability of those strategies to indoor and outdoor comfort in cities.

The mitigation of the urban microclimate will translate into a reduction of building energy demand in the first place (reducing the difference in temperature to be covered as explained in the above sections, see GEPP) and, by improving air quality, it will also allow the integration of low-tech/low-cost bioclimatic strategies that are low-energy by definition.

5.2. MitEM and Human Behavior

The decoupling of CC from the geography and timescale of people's lives, produced by the global scale of the issue and the difficulty for some of grasping the importance of energy and CO_2 savings, produces a considerable impediment to behavioral change [2]. Improving the boundaries of the "*street section*" and re-thinking the activities of that space following systemic "mitig-adaptive" strategies towards MitEM can generate relatively short-term microclimatic improvement that are mutually beneficial for outdoor and indoor comfort, alternative forms of mobility, and new socioeconomic activities. Consequently, these local and short-term improvements to the urban environments potentially have the additional benefit of directly connecting public awareness to the issues of local CC and, indirectly, to that of global CC. This will be more likely to produce the behavioral changes required for the radical transformations needed to enable the transition to a clean, low-carbon, sustainable, and resilient society. In fact, changes in behavioral choices, which are also "*strongly influenced by changes in the built environment*" [17], have been agreed upon as one of the main strategies towards mitigation of CC, with a potential reduction in energy consumption of up to 20% [48]. Hence, focusing on cities will have a more immediate and tangible impact also on societal behavior.

5.3. MitEM and Urban Prosperity

As already mentioned above, the definition of mitigative urban environment should be developed as part of a broader concept of "prosperous streets" as a driver for "urban prosperity", among which a parallel can be drawn. The UN-Habitat's concept of the prosperous city is based not only on economic prosperity but also includes other vital aspects such as quality of life, adequate infrastructures, equity, and environmental sustainability. MitEM offers cities huge scope for the balanced economic growth that is associated with prosperity. This includes opportunities for new types of employment and investments—as the proposals of the Asian Cities CC Resilience Network show [49]: new forms of private/public involvement into urban actions; formal and informal business enhancement; poverty alleviation and inequality reduction; together with new types of infrastructure (*i.e.*, green infrastructure) that would make public spaces more attractive and would increase wellbeing.

In this way MitEM will strengthen the centrality of environmental sustainability in the definition of prosperous cities. In fact, mitigation of the urban microclimate will implement actions that will reinforce the resilience of cities and of the urban society. It could be said that in the long term there will not be prosperous cities if the microclimatic condition of the urban environment is not part of policies and public attention.

5.4. Developed, Emerging, and Developing Countries

"Green" construction standards, substantially based on the high efficiency of buildings, are being implemented mostly in highly urbanized developed countries and they are already showing their limits in meeting the global CO_2 reduction targets. At the same time, such building standards are not gaining consensus in emerging and developing countries due to the unaffordability of the technological solutions at the core of "intelligent" or energy-efficient buildings [43]. Hence, especially in developing countries, there is the need to pursue alternative strategies for "clean energy" buildings. Also the UN recognizes that "*a more suitable strategy for these countries is the use of 'passive' technologies that combine flexibility, accessible know-how and traditional knowledge [...]. Urban areas might want to consider combining such 'passive' methods with some features of modern technology taking advantage of their declining cost in recent years (solar photovoltaic/thermal energy, water harvesting, etc.).*" Considering the abovementioned barriers to the implementation of bioclimatic passive strategies, actions to mitigate the urban environment become crucial to achieve prosperous and conducive urban environments in developed as well as emerging and developing countries.

Building efficiency, although paramount, cannot be the only way to tackle CC at the global and local scale; consistent and parallel improvements of the urban microclimate and environment become crucial to reduce the energy demand for comfort—also through the implementation of passive bioclimatic strategies—and move towards prosperous cities. The demand reduction approach proposed by MitEM, which invests in the mitigation of the microclimate in order to reduce the demand for comfort energy and mechanical systems, also considering transport-related issues, is potentially a highly effective, more comprehensive, and complimentary strategy. In fact, it not only acts on the primary cause of the problem but it can also be a catalyst for additional improvements in the urban environment which will further reduce energy demand and GHG emissions by converting the "*negative loop*" into a positive one.

6. Applicability and Potential Impact

It is necessary to find international agreement on the urban microclimate and environment as a social good [43] and to integrate this concept within the discussion on public spaces and on their quality as a base for urban prosperity as defined by the UN [43,44]. The challenge is to provide cities in developed countries with the opportunity to meet the GHG reduction targets and cities in emerging and developing countries the ground to leapfrog from an energy-based model to a more sustainable and more feasible model of growth. The innovation of the proposed concept is that urban environments can be designed and managed in such a way that their microclimate becomes favorable for outdoor activities and reduces the energy demand of buildings. The microclimate of cities can be mitigated and it could be aligned with the surrounding regional climate (Figure 5). Many studies report on the positive impacts that mitigative strategies (*i.e.*, cool roofs, vegetation, water bodies, cool pavement) have on the urban temperature, but unfortunately there are no cumulative applications of the same at a greater urban scale yet. However, there are some applications at the scale of an urban block that have tried to apply a number of strategies, and, despite the small dimension, have shown a great impact, with a peak summer temperature reduction of up to 3.5 K [49].

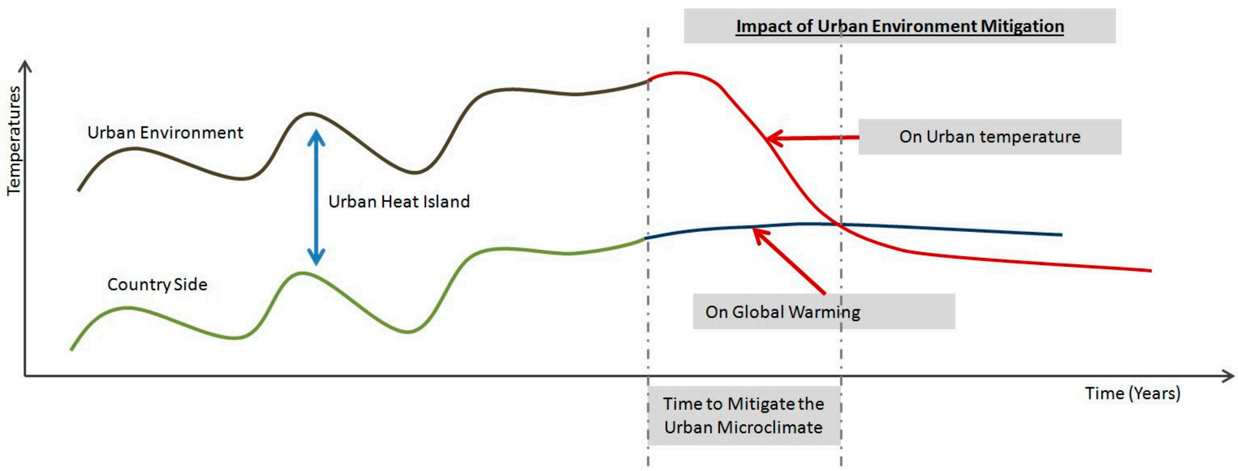

Figure 5. Traditional approach *vs.* proposed approach.

The innovative potential of this concept lies in a new and more holistic way of conceiving urban environments as microclimate modifiers, which if recognized and integrated in (a) international policies and directives; (b) national legislative frameworks; (c) local regulations; (d) performance standards and codes; (e) urban and building design guidance and practice; (f) social awareness and human behavior; (g) economic growth models; and (h) financing mechanisms could greatly enhance urban inhabitants' and authorities' chance to mitigate both the microclimate of their cities and global CC.

The associated innovation potential of the proposed new paradigm is also found in the almost universal relevance of its message. Although urban environments vary greatly between each country, region, and city and between developed, emerging, and developing countries, there is a commonality in the challenge that all urban inhabitants face with respect to local and global CC. Clearly the answers to the same question posed by microclimatic changes will be different and contextual to each city's cultural, socioeconomic, and technological development level. However, the proposed approach of reducing energy dependency and improving outdoor conditions by mitigating the urban environment and reducing the impact of anthropogenic activities and climatic unresponsive buildings is equally valid in developed and in developing countries. In fact, these pathways can unlock the potential for those clean, passive, and bioclimatic strategies that are particularly applicable in developing countries due to their low-cost impact and are equally desirable in developed countries due to their low-carbon potential.

A more direct and immediate innovative potential is that of filling an international gap in policy and regulation by preparing the ground for more specific guidance and recommendations on the characteristics and, specifically, on the mitigative potential of the urban environment on its own microclimate. This gap is not only topical but also implies the poor recognition of the systemic nature of policies, which, if present in some EU countries is at a national level, is certainly not available at the local/municipal level.

7. Conclusions

The potential of urban environments to mitigate their microclimate and to adapt to and mitigate climate change has so far received minor attention at technical and policy level, compared to other approaches such as improvements in building efficiency. However, initial studies and experiments indicate that actions at the urban scale would yield significant and immediate mitigative benefits in improving the local microclimate of cities and reducing the energy consumption of new and existing buildings. This would consequently reduce the GHG emissions of urban buildings. Hence, considering that the urban physical environment and its activities have a major impact on their microclimate and that the GHG emissions of cities are the greatest contributors to CC today, this underexploited adaptive and mitigative potential requires further investigation.

This paper shows the necessity of taking the first step towards a new paradigm of the urban environment by bringing a unique perspective on CC actions focusing on the role of urban environments and their microclimates in the sustainable development of cities. This calls for scientists, policymakers, and stakeholders to work together to produce successful pathways towards improving urban microclimates.

The quality of the urban environment is an equally crucial issue for CC actions in developed, emerging, and developing countries. Its potential to improve microclimates and reduce energy demand and GHG emissions also relates to improvements in the health and social conditions of the urban population, and could unlock new employment and market opportunities. However, this capacity has not been fully recognized yet and, in developed countries, this is proven by the lack of systemic urban policies linked to improvement of the urban microclimate. In emerging and developing countries, this is aggravated by the lack of basic energy policies, even for buildings. The current approach translates into fragmented and sectorial strategies that fail to address the CC mitigative and adaptive potential of the urban environment and do not fully involve its key stakeholders.

More interdisciplinary research is needed to characterize the urban microclimate by analyzing the space in between buildings, its physical boundaries, the related urban activities, and the connected behavior of the main stakeholders. This should be done for different urban and socioeconomic contexts in order to establish a clear and wide-ranging definition of the mitigative environment and its potential to drive cities towards prosperity.

Given the fragmented nature of existing technical solutions, of small scale demonstrations, and of various policies to mitigate the urban environment, there is a need to gather this knowledge further, encompassing good and bad practice examples, in a comprehensive and systhematic manner and to evaluate it under technical, policy and socioeconomic dimensions. The gathering of knowledge, practices, and initiatives will be crucial for determining the potential and constraints of existing and prospective strategies and to define the most effective new pathways. Moreover, this exercise will identify the cross-disciplinary framework and cross-stakeholders involvement within which innovative pathways and systemic strategies need to be defined in order to be effectively implemented and economically grounded on a balanced route towards the improvement of urban environments. The systematization of existing knowledge and related case studies, together with their evaluation and proposed improvements, should be used to inform the decision-making processes of key stakeholders and policymakers at a local level and through international policy channels.

In order to change the current state of the art and transition to the new paradigm of urban environment offered by Mitigative urban Environments and their Microclimates (MitEM), a collective effort involving all levels of society is required. However, when it comes to transformations in the built environment, our society's aspiration for fast economic growth and short-term returns poses substantial barriers to the implementation of mitigative and adaptive CC actions, which are based on different economic models. Therefore, in order to overcome these barriers it is essential to adopt a joined-up approach, which considers many perspectives and interfaces and involves a plurality of society's stakeholders. Transfer of knowledge, collaborative work, and cross-sectorial considerations become fundamental.

Overall, this review shows not only that there is the scientific and cultural maturity to postulate a new concept of mitigative environment and that technical advances and experimentations have demonstrated the feasibility of such a postulation, but that this new proposal fulfills a need and fills a gap. The need is for a new way to consider and conceive our built environment, which will allow for local and global mitigation and adaptation to climate change and the extreme weather events associated with it. The gap is the universal gap that is currently present at policy level, where there is a lack of specific recognition of the impact of buildings on their urban environment and microclimate. The big open question at this point is that even if at a technical and policy level there are the conditions for the postulation of a new paradigm, can it be sustained at a political and economic level, given the values of our current society? In other words, would we as a society be prepared to pay the extra cost for a healthier and more benign urban environment? The answer is in the necessary shift that historically has brought about change when socio-environmental demand and technical offerings converge. The same kind of shift that was undertaken from coal-based heating systems polluting the industrial cities of the 19th century or from poor sanitary conditions in the streets of 18th-century English towns is now necessary to transform our urban environments from recipients of noise, waste heat, and poor air quality into positive microclimates that contribute to both the outdoor and indoor comfort of our urban living.

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Author Contributions

The authors have equally contributed to the article.

Conflicts of Interest

The authors declare no conflict of interest.

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