Advances in 21st Century Human Settlements

Napoleon Enteria
Matteos Santamouris
Ursula Eicker *Editors*

Urban Heat Island (UHI) Mitigation

Hot and Humid Regions

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Napoleon Enteria · Matteos Santamouris ·
Ursula Eicker
Editors

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Editors
Napoleon Enteria
College of Engineering and Technology
Mindanao State University—Iligan Institute of Technology
Iligan, Philippines

Matteos Santamouris
Faculty of Built Environment
University New South Wales
Sydney, NSW, Australia

Ursula Eicker
Gina Cody School of Engineering and Computer Science
Concordia University
Montreal, QC, Canada

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Preface

The rapid development of urban areas in hot and humid regions has led to increases in urban temperatures, a decrease of urban ventilation, and a transformation of the once green outdoor environment into solar-energy-absorbing concrete and asphalt. This situation has increased the discomfort both outdoor and indoor and decreased air quality. Also, the energy consumption and CO_2 emissions of urban areas are still increasing despite many efforts to improve efficiency of buildings and energy systems.

The term urban heat island (UHI) refers to the current increase in urban temperatures due to high thermal load, problems related to urban ventilation, and the increased usage of asphalt and concrete. UHIs negatively affect the health of urban dwellers and increase urban cooling energy consumption. The presence of UHIs, in combination with global warming, means that the temperatures in metropolitan areas within hot and humid regions are expected to increase, as the demand for more thermal comfort and better ventilation results in increased usage of air-conditioning and ventilation systems.

The UHI phenomenon in hot and humid regions affects the daily lives of the populations living in these areas—it increases the urban temperature, which results in increased discomfort. Furthermore, as the outdoor temperature increases, the operation of air-conditioning systems increases, which further affects the outdoor temperature. This will increase the urban temperature, which complicates the UHI phenomenon in hot and humid regions as energy and environmental concerns become interconnected. Hence, passive and active concepts and technologies are being implemented to mitigate the effects of UHIs in hot and humid regions.

The research and development of concepts and technologies intended to mitigate the effects of UHIs has advanced especially in countries within hot and humid regions, as urban centers experience temperature increases, especially during the hot summer season. As UHIs are expected to be of growing concern in many urban areas in hot and humid countries, the development and application of UHI mitigation concepts and technologies will have a significant impact on public health and energy consumption.

This book compiles the concepts and technologies associated with the mitigation of UHIs that are applicable in hot and humid regions. Several experts in the field were invited to contribute chapters on the reduction of UHIs in different areas to provide readers, researchers, and policymakers with insights into the concepts and technologies that should be considered when planning and constructing urban centers and buildings. This book offers solutions for the problem of increasing UHIs in hot and humid climates. The chapters discuss passive and active methods that can be incorporated during urban planning, urban renewal, building design, and building retrofitting processes.

We acknowledge with gratitude each of the global experts who have fully supported and contributed chapters. With their support, this book has become a guide for urban planners, building designers, and policymakers with regard to the consideration of the urban heat island (UHI) phenomenon in hot and humid regions. We are grateful to Springer and the staff for the support given to us from this book's conceptualization through to its publication. We are also thankful to our families for their support during the entire process of producing this book.

We hope that with this book, urban planning and building design in hot and humid regions will not complicate the UHI problem. Hence, it will contribute to lessening the impact of UHIs through the application of the latest concepts and technologies for the reduction of urban temperatures.

Iligan, Philippines Napoleon Enteria
Sydney, Australia Matteos Santamouris
Montreal, Canada Ursula Eicker

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About the Editors

Napoleon Enteria is Professor of mechanical engineering at Mindanao State University—Iligan Institute of Technology, Philippines. He has worked as research specialist at Building Research Institute, a research staff member at Tohoku University for industry–government–academe collaboration, a scientist at the Solar Energy Research Institute of Singapore of the National University of Singapore, and a global center of excellence researcher at the Wind Engineering Research Center of the Tokyo Polytechnic University, Japan. He founded the Enteria Grün Energietechnik, a research and technology consulting for tropical climate. He has participated in collaborative projects with research institutes, universities, and companies across several countries. He is Associate Editor with some of the international journals. He also serves as Guest Editor of some of the important special research issues.

Matteos Santamouris is Scientia Professor and Professor of high-performance architecture at the University of New South Wales, Australia. He is also Professor at the University of Athens, Greece, and Visiting Professor at The Cyprus Institute, Metropolitan University of London, Tokyo Polytechnic University, Bolzano University, Brunel University London, and National University of Singapore. He has served as Director of the Laboratory of Building Energy Research at the University of Athens and is Former President of the National Center of Renewable and Energy Savings of Greece. He works as Editor in Chief and Member of the editorial board of several international journals. He has been Guest Editor for twelve special issues of various scientific journals. He is considered an expert by various international research institutions.

Ursula Eicker is the Canada Excellence Research Chair (CERC) for Next-Generation Cities at Concordia University, Montréal. She has held leadership positions at the Stuttgart University of Applied Sciences and its Centre for Sustainable Energy Technologies. She has been leading international research projects in the fields of energy efficiency in buildings and sustainable energy supply systems for more than two decades. At Concordia, she leads an ambitious research program to establish pathways toward new tools, technologies, and strategies for zero-carbon cities. Her research interests include the renewable energy systems, smart buildings, urban energy simulation, sustainable transportation, and smart waste and wastewater management. From solar modules to cooling systems to tech industrialization, she has the distinctive experience of working across sectors, from the laboratory to the factory and beyond.

Morphology of Buildings and Cities in Hot and Humid Regions

Napoleon Enteria, Odinah Cuartero-Enteria, Mattheos Santamouris, and Ursula Eicker

Abstract Hot and humid regions consist of the tropical climate, Middle Eastern climate, and Mediterranean climate. Such regions are normally located near the equator but also include dessert regions located far from the equator, such as the Gobi Desert. These regions experience uncomfortable thermal comfort levels due to the high outdoor air temperature and, in some cases, high humidity. This situation makes it challenging to provide thermal comfort in these regions. The increased economic activities in most of the countries in hot and humid regions have changed the morphology of urban areas, cities, buildings, and houses. The increase in urbanization affects the outdoor and indoor environments of buildings and houses. The increasing urban temperature due to the increase of heat generation from people, cars, appliances, and other human activities affect the chemical and biological situations of urban areas. The increasing outdoor air temperature due to urban heat generation (aka, urban heat island) in hot and humid regions worsens the already unpleasant outdoor air conditions. It has also resulted in an increase in the use of air conditioning systems and energy consumption as the heat sink temperature (outdoor air) increases. With this, the difference between the indoor air and outdoor air temperature has increased.

Keywords Hot and humid regions · Urban heat island (UHI) · Mitigation techniques · Cities and urban centers · Buildings and houses

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N. Enteria (✉)
Iligan Institute of Technology, Mindanao State University, 9200 Iligan, Philippines
e-mail: enteria@enteria-ge.com; napoleon.enteria@g.msuiit.edu.ph

O. Cuartero-Enteria
Surigao Del Sur State University—Cantilan Campus, 8317 Cantilan, Philippines

M. Santamouris
University of New South Wales, Sydney, NSW 2052, Australia

U. Eicker
Concordia University, Montreal, QC H3G 1M8, Canada

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1 Introduction

The economic development of different countries in hot and humid regions has different accounts. The development of countries in hot and humid tropical countries in South East Asia has centered on the development of natural resources [1] and commercial and manufacturing activities [2], which have resulted in a better standard of living and urbanization. The case of Middle Eastern countries has resulted in the booming production of oils, which has resulted in the development of metropolitan areas [3, 4]. Situations in other regions in Latin America, North America, and the Mediterranean are due to increased economic activities owing to a combination of natural resources development and manufacturing-commercial operations, which, in turn, have resulted in urban development and an influx of people [5, 6].

The increase of populations of urban areas, either due to permanent migration or movement during working hours, has led to extensive energy consumption [7] for transportation, houses, food establishment, offices, health centers, etc. [8]. The increase of building energy consumption has resulted in an increase in heat emission as the energy consumed in those establishments is intended to produce better indoor comfortable conditions (e.g., better thermal comfort, air quality, lighting, and energy for work equipment and personal gadgets) [9]. In addition, the systems that transport workers and goods create environmental concerns [10–12] in addition to climatic conditions (e.g., heating due to the absorption of solar energy by urban structures) [13].

Due to the large influx of people in concentrated commercial, trade, manufacturing, and urban areas, heat generation has increased [14, 15]. The flourishing of urban areas and centers has resulted in high concentrations of people, transportation services (public and private), restaurants, and other amenities to provide comfort to the people in the surrounding areas [16]. Large-scale and quickly developing urban centers have created stress related to supporting the requirements of the general population living and working around these areas. In turn, the situation has resulted in environmental degradation [17, 18]. Environmental degradation has affected the environment's ability to support a healthy population as emissions increase [19].

The rapid development of urban areas and cities, which have resulted in unplanned urban planning and zoning, have created an imbalance between natural and artificial structures around densely populated areas, which, in turn, has resulted in unhealthy environmental conditions [20]. In hot and humid regions, these conditions have furthered the localized heating of urban areas owing to heat generation, absorption of solar energy, and the effect of hampered urban ventilation [21–23]. The resultant heat increase—the so-called urban heat island (UHI)—further complicates the situation of hot and humid regions [24, 25]. This has resulted in the further utilization of artificial mechanical cooling and ventilation systems [26], which generates additional urban anthropogenic heat [27].

Due to the limitations of horizontal space development, vertical development has become more widespread in urban areas and cities. High-rise buildings containing offices, residential complexes, amenities, and other vertical structures, have become the norm in highly urbanized areas; these structures lead to a high building density and contribute to UHIs [28]. The vertical development of urban areas also increases the anthropogenic heat and hampers the flow of natural air ventilation while increasing pedestrian-level airspeed and lowering solar energy absorption due to sun-shading [29, 30]. Buildings affect solar irradiation absorption, which either helps with heating or cooling urban areas [31]. In compact cities, the street-level thermal environment affects the outdoor thermal comfort, the urban environment, and pollutant dispersion [32].

With the large-scale influx of people in urban areas and cities, housing developments in nearby areas flourish to cater to the needs of the people in the middle and upper echelons of society [33–35]. The development of subdivisions eliminates the natural vegetation of the areas around the urban areas and cities [36]. The alteration of the land to cater to the needs of urban growth has resulted in increased air temperature [37]. Hence, the preservation of nature should be considered in all land development projects [38]. Otherwise, it will result in biodiversity loss [36].

2 Buildings and Houses

The buildings and houses in hot and humid regions evolved since the start of civilization until the present generation. Numerous structures have been changed regarding their design, selection of materials, methods of construction, and operation. From passively operated buildings and houses in previous years to the advanced and smart-operated buildings and houses in modern times are typical in the regions.

2.1 Old Situation

In previous years, buildings and houses were designed and constructed based on the available materials, safety considerations, and climatic conditions. In the Middle Eastern climate, the buildings and houses are designed based on the available materials, such as mud, clay, and stones, and the hot climate [39–42]. In the hot and humid climates of tropical regions, buildings and houses are typically constructed using wood [43–45]. Variations of the design and construction can be seen based on records [46]. From these designs and methods of construction, it can be concluded that the design of old houses and buildings is solely based on the materials present and the climatic conditions [47].

The maintenance of safety and a comfortable environment based on the building materials, design, and construction were important considerations in ancient times [48–50]. In the hot climate of the Middle East, parts of South America, and the Mediterranean area, different cooling and ventilation techniques were applied [51–53]. Local materials that could minimize heat transfer (thus minimizing the indoor heating effect) were used [54, 55]. Natural ventilation was also applied based on the design of buildings and houses [51].

2.2 Present Situation

The structural design of buildings and houses in hot and humid regions has changed as science and technology have changed [56–58]. Today, buildings and houses are mostly designed and constructed using concrete, steel, and glass [59]. These designs absorb a lot of solar energy and increase the indoor temperature [60]. Buildings in hot and dry regions such as the Middle East become solar energy absorber due to the building materials and glass facades. Thus, the application of solar energy reflectors [61] and thermal storage [62] could minimize indoor heating. The same pattern (e.g., the application of sun shading and heat insulation) has been observed in other hot and humid regions, such as tropical regions of Asia and Latin America [57].

Because of the demand for better indoor thermal comfort, air quality, and energy conservation, buildings nowadays are designed to have air handling systems that can provide the needed indoor thermal and air quality environment for different building requirements [63]. With the structure of buildings absorbing a higher percentage of solar energy, the energy demand for maintaining a comfortable indoor environment has caused the buildings in hot and humid regions to consume a large percentage of the energy required for the building sector [64]. Buildings situated in central areas or urban centers are expected to continuously operate air handling systems to maintain a comfortable indoor environment [65]. Hence, making the indoor environment thermally comfortable makes the outdoor environment more uncomfortable due to energy consumption and heat emission [66, 67].

2.3 Future Situation

Environmental concerns have become intense due to global warming and climate change, which are caused by large amounts of greenhouse gas emissions, to which the building sector has contributed a sizable percentage [68, 69]. Buildings and houses are to be designed to minimize the absorption of solar energy to avoid indoor heating [70, 71]. Buildings are designed to be sustainable by utilizing recyclable and organic materials in their construction [72, 73]. With the application of advanced building technologies in hot and humid regions and with the consideration of climatic conditions such green walling [74] and smart windows for passive ventilation [75], buildings will become energy efficient and sustainable, thereby having a smaller impact on the outdoor environment [76]. This will create smart buildings whose operation depends on the changing requirements of the occupants and the outdoor environment [77].

Due to concerns about the environmental impact and energy requirements for providing the needed indoor environment, buildings and houses are to be energy-efficient with clean energy generating capabilities [78]. In the future, buildings and houses are expected to be this to minimize energy waste while providing comfortable air quality in the indoor environment [79]. With advancements of building technologies, buildings and houses are expected to minimize their contribution to increasing the surrounding temperature from the solar energy absorption [11], constraining urban ventilation [80], and emitting heat from their air handling systems [81].

3 Urban Centers and Cities

Civilization starts when people build cities for trade, commerce, government centers, and areas for living. The convergence of people and buildings changes the structure of urban centers and cities. This situation creates stress on the environment, as cities and urban centers become unsustainable due to the environmental impact created within an outside its boundaries to cater to the needs of the population.

3.1 Old Situation

At the start of civilization, cities were created that tended to change the balance of the interactions between the people and the environment, as the people came to demand more resources from the environment to support their existence [82, 83]. The availability of different resources and infrastructures resulted in an increase in cities' populations, which also resulted in an increase in environmental concerns [84]. Cities of the old times were built near the available needed resources and materials (e.g., water, food, mud, clay, stones, timber) [85]. The development of old cities affected the resources available in nearby areas and resulted in the destruction of natural resources such as water resources, soils, and other resources [86, 87].

The rapid development of older cities and urban areas created discomfort in hot and humid regions as a large influx of people and a build-up of different infrastructures created different methods to maintain thermally comfortable environments [88]. Old technologies (e.g., wind catchers, sun shading, evaporative cooling, prevailing wind ventilation) were created to minimize the effect of air temperature [89–91]. The innovations of the people living in these times in hot and humid regions contributed to minimizing the effects of the increase in urban temperature [92].

3.2 Present Situation

With the rapid development of urban planning and building sciences, the zonal planning of urban areas has become popular [93, 94]. In hot and humid regions, the redevelopment of cities and urban areas depends on each country's capabilities through proper investigation [23, 95]. In highly developed and economically stable countries, existing cities have been redeveloped with proper urban planning to cater to the needs of the local populace [96], minimize the concentration of man-made structures [97], and apply greening around urban areas [98]. However, in developing countries, proper urban redevelopment has become a concern, as it will involve massive investment and the involvement of different stakeholders [99, 100].

Proper urban planning has resulted in the minimization of the increase of urban temperature, air pollution, and the usage of air conditioning and ventilation systems [101]. Moreover, it also contributed to the greening of different urban areas, which resulted in an increase in urban air quality [102]. In well-planned urban centers and cities, urban ventilation has contributed to a reduction in air pollution, urban temperature from solar energy absorption, and heat emitted from air handling systems, equipment, devices, and people [22, 103]. With proper urban planning, the use of the public transportation systems can be minimized as people can use different transportation modes, such as walking, biking [104].

3.3 Future Situation

With the global concern of energy and environment [105, 106] coupled with increasing urban population [107], proper urban planning will become an important consideration in the redevelopment of urban areas and cities, to minimize the usage of common urban transportation methods [108] and typical energy sources by promoting clean energy sources [109, 110]. Urban areas are expected to minimize the build-up of heat, pollution, and the utilization of different urban greening technologies, which can contribute to the minimization of UHIs [9, 111–113]. This is possible by synergizing natural and artificial structures to be built side by side [114, 115]. It can also be done by means of utilizing solar energy for different applications [116].

The application of advanced urban planning and building sciences could create a positive impact on the comfort, wellbeing, and health of the urban environment and the people living in these environments [117, 118]. This creates a healthy population and minimizes negative impacts on the environment by using smart technologies [119–121]. Redeveloped and well-planned urban centers and cities attract investment and development as people tend to be more productive (e.g., no traffic, comfortable environment, a healthy population, and lower pollution) [78, 122, 123]. This situation has a great impact on whole countries, as well-planned urban centers and cities have a greater effect on the economy through which the concept of smart cities will be realized [124–126].

4 Conclusions

This chapter describes the evolution of cities and buildings in hot and humid regions. Hot and humid regions' development further contributes to the increase of UHIs. As these regions are already hot, the situation will become more complex if it is not properly addressed soon.

Hence, to minimize the effect of UHIs in already hot and humid regions, proper urban planning will be introduced. Urban greening will be an important component with zoning to minimize the traffic situation. Application of different technologies to reduce pollutant emissions, and the use of building materials that minimizes the absorption of solar energy will be minimize the increase of urban temperature.

With this, it is expected that current urban planning practices will be reviewed, and future urban planning and zoning methods will be strictly implemented. With the dynamic economic situation and technologies under development, the development of urban centers and cities will be prepared to apply future technologies through which the environmental, economic, and technological demands of urban dwellers will be addressed.

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Assessment of the Effects of Urban Heat Island on Buildings

Liangzhu (Leon) Wang and Chang Shu

Abstract Climate change and global warming have been indisputable as supported by mounting evidence of more extended, severe, and frequent occurrences of extreme weather events (EHEs), in particular, summertime heatwaves in recent years. EHEs often interact with buildings in urban area centers, which are densely packed by building blocks with vulnerable populations: the homeless, elderly, children, socially disadvantaged people, the physically challenged, or the sick, creating a unique natural phenomenon, urban heat island (UHI). This chapter covers a comprehensive effort to assess the UHI impacts on buildings and the potentially vulnerable populations through a series of surveys and field measurements in schools and hospitals, and a multi-scale climatic modeling framework from global and regional climates, urban microclimate, to building scale simulations. General methodologies are reported in detail for a better understanding of the levels of impacts by UHIs on buildings, e.g., excessively high indoor temperatures, energy demands and peak loads, and on people, e.g., indoor overheating risks. The effort is essential for developing measures and strategies to mitigate the UHI impacts on buildings and occupants for the current and future climates.

Keywords Climate change · Urban heat island · Extreme heat event · Vulnerable · Survey · Field measurement · Overheating · Thermal comfort · Energy load · Mitigation · WRF · UHI · Microclimate · Weather forecasting · Multi-scale simulation · Digital twin · CFD · Urban building energy model

1 Introduction

It is unequivocal that the global climate has been consistently warming and projected to worsen in the future [1]. Furthermore, extreme climate events such as heatwaves are

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L. (Leon) Wang (✉) · C. Shu
Department of Building, Civil and Environmental Engineering, Centre for Zero Energy Building Studies, Concordia University, 1455 de Maisonneuve Blvd. West, Montreal, QC H3G 1M8, Canada
e-mail: leon.wang@concordia.ca

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projected to increase in frequency and intensity [2]. Overheating of building interior spaces as may arise from such climate change and extreme heat events (EHEs) have been identified as a major concern to the comfort and health of building occupants, particularly of the vulnerable people, such as the homeless, elderly, children, socially disadvantaged people, the physically challenged or the sick. Urban area centers that are subject to the urban heat island (UHI) effects may exacerbate the risk of the overheating events in that the indoor thermal conditions can reach excessive values over a prolonged period. In a recent heatwave of June 30–July 7, 2018, up to 66 deaths were reported in Montreal with most of them being older residents, such as those people who suffered from mental or chronic illness and addiction more easily than the others, as they were left without access to air conditioning in vulnerable communities of the city center [3].

Buildings play a significant role in limiting the risk of overheating events [4]. Buildings influence the indoor thermal conditions to which occupants are exposed most of the time, given the fact that people spend approximately 80–90% of their time indoors [5]. Buildings that house vulnerable people and/or with poor management of indoor thermal conditions will suffer the most from the effects of overheating. It was found that most of the 66 heat-related deaths during the 2018 extreme heat event in Montreal happens in the community, and still, around 11 happened in hospitals [6, 7]. The resilience of hospitals against EHEs may help to reduce the mortality and morbidity of vulnerable groups of people, e.g., the elderly, sick, and those having mental illnesses [8]. The high indoor temperature in schools may also violate the academic performance of the children students aged between 8–14 [9]. The risk of overheating in mild climate area has been quantified by simulation studies, and more field monitoring are needed to cope with the future overheating problem due to the increase of I.T. equipment usage in classrooms and global warming trend [10]. The severity of the indoor conditions depends on many factors of buildings: types (houses, retirement homes, apartment buildings, schools, hospitals, etc.), internal space usage (occupant density, internal heat gains), construction characteristics (insulation levels, window proportions, solar shading, the orientation of facades), and building operation (air-conditioning use, natural ventilation, etc.) [11].

However, studies on building indoor thermal conditions as relating to the outdoor conditions are still minimal to enable the healthcare and building code organizations to establish threshold exposure limit of temperature and relative humidity to protect the health of the vulnerable population, which could be attributed to the following limitations and challenges: (1) There is a significant lack of field monitoring data of outdoor and indoor thermal environments for different building types. As a result, no reliable benchmarking data are available to support the assessment of the resilience level of the existing building stocks against overheating and the establishment of threshold overheating exposure limit criteria. (2) There are limited simulation studies for establishing correlations between indoor and outdoor conditions, and the development of climate-adaptive mitigation strategies for developing associated guidelines against overheating. Accurate whole building performance simulations require adequate validations against field monitoring data. (3) The whole building simulations also need accurate and detailed inputs of surrounding ambient conditions, which were often based on global/regional-scale weather and climate change data in the previous studies without considering the impacts from local microclimate environment down to building scales [12]. A scientific challenge remains to derive reliable climate change information at a spatial resolution that is relevant for building-scale impact assessments (e.g., <1 m) as opposed to the resolution at which they are generated at a global scale (e.g., >100 km) and downscaled to regional level also taking into account the uncertainty in projections as contributed due to the existence of multiple Global Climate Models (GCMs) and greenhouse gas emission scenarios. This chapter introduces a showcase study in Montreal, Canada, to assess the overheating risks in buildings as a result of urban heat island effects. In this study, (1) a series of multi-year field measurements on multiple buildings are conducted to determine the indoor condition exposure levels as related to the outdoor conditions to help set up temperature and humidity threshold limits for vulnerable occupant health; (2) A series of simulations, calibrations, and validations based on the field measurement and urban-scale microclimate data are conducted. (3) A novel integrated regional-urban-building-scale simulation platform is developed to study the impact of current weather and future climate change on building indoor environments as a result of the urban heat island. Note that for generality, this chapter focuses on the introduction of approaches and methodologies instead of specific data obtained from this study.

2 Field Measurements of UHI Effects on Buildings

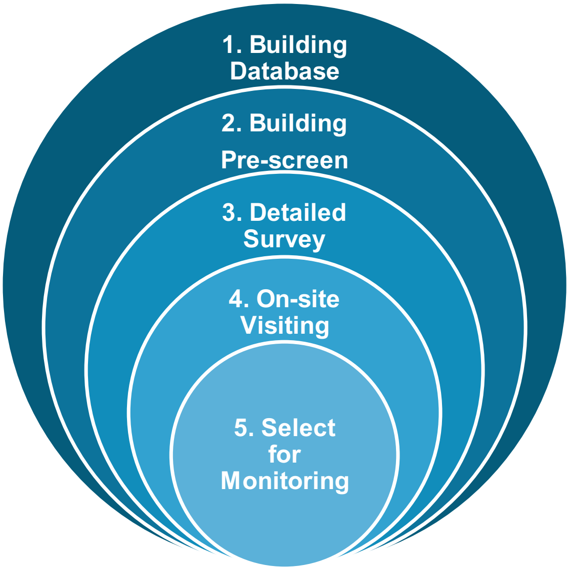
2.1 Building Selection and Site Visits

In this study, field monitoring is carried out for a limited number of school and hospital buildings for three years. Therefore, determining the best combination of buildings as regards to the most vulnerable to EHEs can be a significant challenge to ensure capturing both the EHE and indoor overheating problems during the long-term monitoring program. A five-step guideline for the screening and selection of buildings for field monitoring is given in Fig. 1.

In the first step, a vast building database for all the hospital buildings and school buildings in Montreal were obtained from the official institutes. A total of 200 hospitals and 396 school buildings across the Montreal island were provided at first with their locations (Fig. 2).

In the second step, a pre-screening of the building database was conducted to further reduce the scope for building selection. An investigation on previous heat-related deaths during EHEs showed that the location and distribution of emergency calls and the heat-related deaths [7, 13] attributed to EHEs; these are highly related to the urban heat island intensity as given in Fig. 2. The large dataset of buildings were first filtered by the types of buildings. For hospital buildings, only three types of hospitals with long-term residents are considered, i.e., residential and long-term care centres (CHSLD), hospital center (C.H.), and rehabilitation center (C.R.). For

Fig. 1 Procedure for screening and selection of buildings for field monitoring



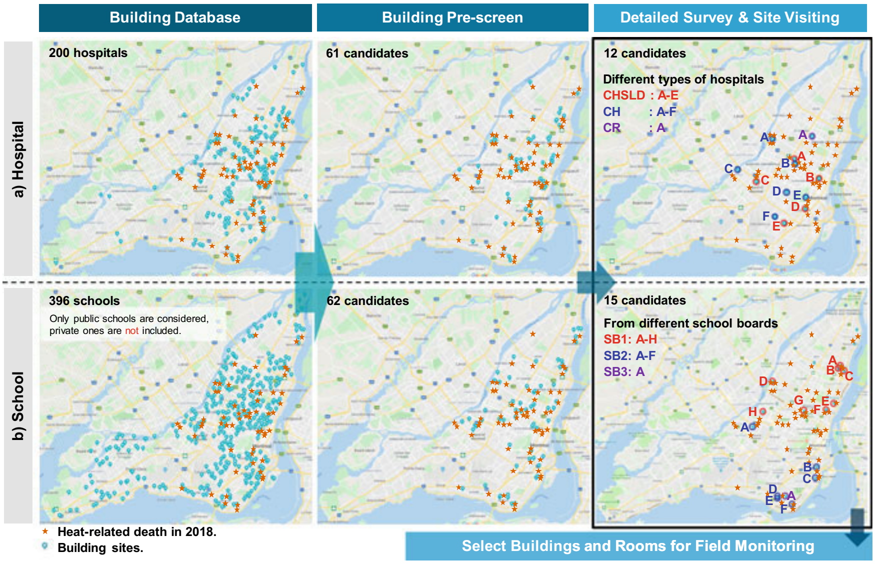


Fig. 2 Distribution of the school and hospital buildings in Montreal island for survey and site visiting screening

school buildings, only preschools and primary schools with students aged between 8 and 14 are considered. An investigation on previous heat-related deaths during EHEs showed the location and distribution of emergency calls and the heat-related deaths attributed to EHEs; these are also highly related to the urban heat island intensity [7, 13]. Most of the health events (i.e., heat-related deaths and emergency calls) happened in areas with intensive heat island problems, indicating dwellings in these areas may have had a higher exposure during the EHE, and the buildings in these areas may be more vulnerable to overheating issues. Therefore, the location of the buildings and their surrounding environment become an essential criterion for the pre-screening of the buildings. The surrounding conditions of the buildings can be first studied from Google Earth (G.E.) and street views. A graphic set of buildings were created from the southern view from Google street views to study the orientation of the buildings and to figure out if there are imperious or natural green open spaces, parks, tall plants and high buildings adjacent to the buildings. The surrounding information can also be confirmed later during the site visiting. After the building pre-screen process, 61 hospitals and 62 schools are targeted plotted in Fig. 2 to show their locations to compare with the heat-related death locations in 2018. A graphic set of each of the buildings was created from the southern view on Google street maps, and the buildings were filtered using the following criteria:

1. Schools mainly with children aged 8–14;
2. Hospitals with long-term residents;
3. The building location is close to those sites where deaths had been previously noted;
4. Buildings with the longer façade facing the north–south direction
5. Buildings that were not close to green areas or parks
6. Buildings located in a high-density neighborhood and close to major streets or parking lots having large areas of impervious land cover without any shading.

For the reduced set of candidate buildings, a building information survey campaign was prepared for gathering detailed information in the third step. A building information survey form was distributed to the buildings to obtain information on construction details, building equipment, and related information. The survey sheet also contained information in which the study objectives were provided and that to explain the possibility for building managers to support the study. The building information survey form is organized into five sections:

1. General information of buildings: building name construction year, number of floors, number of occupants, etc.
2. Building performance and occupant behavior: thermal comfort and historical heat-related health events, building activities, overheating complaints, and relevant measures to mitigate impacts of overheating.
3. HVAC system: type of system, fresh air system, cooling system, ventilation, etc.
4. Building envelope: type of envelope construction, materials, window type, window-wall-ratio, etc.
5. Building plans.

The fourth step is to conduct on-site visits and gather first-hand building information. For hospital buildings, three types of hospital buildings with long-term residents are considered including CHSLD, CH and C.R. For school buildings, a total of 15 school buildings from three school boards are visited. The selection of schools is only limited to preschool or primary schools with the ages of the students between 8 and 14. A total of 14 residential buildings are provided for the site visiting. The visits were conducted in July 2019 for hospital sites, September 2019 for schools, and February 2020 for residential buildings. Due to the breakout of COVID-19, we have only completed site visits to six residential buildings. Most of the visited residential buildings are in the north and east of Montreal Island.

At last, in the fifth step, decisions can be made after a comprehensive analysis of all the information from the previous steps to evaluate the visited buildings. The overall distribution of selected buildings, the real conditions of the building, and the willingness of collaborations of the building owners should be considered comprehensively.

2.2 Summary of Building Information and Selection Results

As is mentioned in the previous section, the building information survey consists of five parts covering comprehensive aspects of the building. But it was found that it is hard to know the real performance of the buildings and hard to conclude the occupant behavior and the HVAC system based on the concise answers to the survey sheet. Although the building information survey is conducted before the site visiting, it seems much efficient to analyze and extract useful information from the survey forms after the site visitings. We therefore first classified the buildings into two groups of categories according to the site investigations: (i) buildings with overheating complaints and (ii) without complaints, as shown in Table 1. Then the potential factors considered in the survey forms are analyzed to find out the most valuable cases to study the overheating problems in the summer.

After the survey and site visiting, it was found that a cooling system is seldom used in schools. Among the 15 buildings visited, only SB1-H has a cooling system in a new building section. Most of the school buildings have fresh air supply to the corridor, gym, and basement. The buildings are usually cooled through passive

Table 1 Overheating complaints in the visited buildings

Bldg. types	With complaints	Few complaints
Hospitals	CHSLD-A, B CH-A, B, D, F	CHSLD-C, D, E CH-B, C, E CR-A
Schools	SB1-A, B, D, G SB2-A, B, D, E	SB1-C, E, F, H SB2-C, F SB3-A