The influence of building height variability on natural ventilation and neighbor buildings in dense urban areas

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Abstract

Urban Heat Islands (UHI) have been associated with urbanization. In dense urban areas, when simulating the energy performance of a new building, understanding the UHI effect on the microclimate is critical. With reported increases in the center of large cities up to 7℃ higher than the local weather station, at times, this is a critically important piece of information. The problem for the simulationist is establishing the appropriate microclimate 'correction'. It is well-known that the height of new buildings affects the surrounding microclimate, influencing urban wind flow significantly. The vertical temperature lapse rate can be significant in buildings of 30 stories or more. The effect of UHI depth on the lapse rate and the effect of the altered wind flows on the UHI are less well-known. A systematic literature review has been conducted to establish the level of documentary evidence for the relationship between UHI depth and temperature lapse rates and building interaction with the turbulent wind boundary layer. The goal is to establish a basis upon which naturally ventilated tall buildings might be accurately modeled within dense urban environments.

Introduction

This study looks to find the evidence in the literature on which to base accurate modeling to wind and temperature in dense urban areas affected by Urban Heat Island (UHI) issues. The goal is to establish an evidence for managing the modeling of building and neighborhood height for better natural ventilation in dense urban areas.

Natural ventilation offers the opportunity to achieve a great reduction of energy consumption at the same time as it improves the indoor air quality. In an area when increasingly cities are looking to remove cars from city centers, and vehicle fleets are becoming electrified, it is possible to imagine that occupants in office buildings in dense urban areas may have fresh outdoor air available to assist the maintenance of high-quality thermal comfort.

The Urban Heat Island (UHI) effect, as a phenomenon of air temperature increase produced by urbanization, is not often considered in current building energy simulation (Bruno et al., 2012). One of the reasons is that current thermal simulation practice is based on typical meteorological year (TMY) data or actual meteorological year (AMY) data. However, the widely used TMY and AMY files originate from long-term weather data stations outside of urban, typically at airports(S. and W., 2008). Since building sites tend to be urban, a bias in performance metrics is introduced by using rural site weather data due to the UHI phenomenon(Arnfield, 2003).

Natural ventilation efficiency is affected by variable factors like wind speed and direction, especially wind movement around the building. The urban form, in particular, individual building height, influences the wind movement in urban areas leading to microclimate change. This research focuses on identifying relevant research on the height of buildings as a parameter which influences wind movement, and the increase of wind speed with height in the Urban Boundary Layer, and also on temperature stratification in the atmosphere. These are well-known phenomena. They can be modeled in software like EnergyPlus where the increase of wind speed with height can be modeled using a power law, and the Lapse Rate of 0.65℃ decrease in temperature per 100m height increase can also be modeled. What is less known is the interaction of these parameters with Urban Heat Islands. Is city-scale CFD(Ai and Mak, 2013) an essential part of every building model investigation?

If a new large scale tower is placed amongst a large city of low-rise buildings, the effect of the new building on the UHI, on the wind in the street and the structure of the lapse rate of temperatures is problematic. This paper is exploring what the literature can tell us on this subject.

Methodology

This systematic review of the topic of microclimates focusing particularly on the interactions of Urban Heat Islands, vertical temperature lapse rates and tall buildings' influence on urban wind flows has examined over 200 relevant references.

According to early observations, the Lapse Rate is close to 0.65 ℃/100m(Brunt, 1933). Thus the temperature outside the top floor of a 30 stories building will be 0.65 ℃ cooler than the bottom. In the atmospheric boundary layer wind speeds also increase with height. Buildings in with the velocity increasing the air pressure increases at the same time which has the potential to increase heat loss from upper stories of tall buildings. In dense urban areas, the maximum temperature difference between the rural temperatures and those in the center of a UHI could be as

Table 1: Search terms within databases (Date of last search:13 November 2016)

Database	Search terms
ScienceDirect	TITLE-ABSTR-KEY(urban heat island) and TITLE-ABSTR-KEY(height or depth) and TITLE-ABSTR-KEY(temperature) and TITLE-ABSTR-KEY(simulation) and TITLE-ABSTR-KEY(building) and TITLE-ABSTR-KEY(wind)
Scopus	TITLE-ABS-KEY (urban heat island) AND TITLE-ABS-KEY (height OR depth) AND TITLE-ABS-KEY (temperature) AND TITLE-ABS-KEY (simulation) AND TITLE-ABS-KEY (building) AND TITLE-ABS-KEY (wind)
ProQuest	all(urban heat island) AND all((height OR depth)) AND all(temperature) AND all(simulation) AND all(building) AND wind
Engineering Village	(((((((urban heat island) WN KY) AND ((height or depth) WN KY)) AND ((temperature) WN KY)) AND ((simulation) WN KY)) AND ((building) WN KY)) AND ((wind) WN KY))
SAGE journals	urban in all fields and heat in all fields and island in all fields and height or depth in all fields and temperature in all fields and simulation in Abstract and building in Abstract and wind in Abstract

much as 6 to 12℃, depending on city size(Oke, 1973). If a new high-rise building is placed among low-rise buildings in dense urban areas, the effect of the new building on the UHI, on the wind in the street and the structure of the lapse rate of temperature is problematic.

A systematic review has been conducted on the influence of building height. The issue of height or depth of UHI in face of large-scale towers penetrating the Urban Canopy Layer (UCL) is explored. The impact these parameters on the potential for openable windows to provide sufficient natural ventilation for summer cooling is explored.

Search process

The search process identified papers with a search strategy across five literature databases (English language): ScienceDirect, Scopus, ProQuest, Engineering Village and SAGE journals. According to my knowledge, these five databases are the most popular databases for building science and they could cover the vast majority of relevant research. In ScienceDirect, Scopus and Engineering Village, the initial search terms in the article title, abstract or keywords were: ‘Urban Heat Island’, ‘height or depth’, ‘temperature’, ‘simulation’, ‘building’ and ‘wind’. This study is mainly focused on building height influence on depth of UHI, wind flow and temperature gradient, So when searching the associated papers, the limitation key works are “UHI”, “height or depth”, “temperature” and “building”. And as simulation could be an efficient method, it also has been added into search limitation. In ProQuest the search terms were searched anywhere except full text which is the only option same as title-abstract-keywords. If search the full text in ProQuest, the results were too many and lots of them less relevant. In contrast, the SAGE journals search area was all fields as the search results were rare when limited title- abstract-keywords. Then in SAGE journal, the initial search terms in all fields were: ‘Urban Heat Island’, ‘height or depth’ and ‘temperature’. The search terms in the abstract were: ‘simulation’, ‘building’ and ‘wind’. Air pollution is out of this research area, results with pollution or pollutant were excluded. The exact search terms used were shown in Table 1.

Data extraction

The following data were looked for in the studies found through the search strategy: (1) temperature gradient(2) difference between Urban Canopy and Urban Boundary Layer temperature or wind (3) type of building (4) measured simulation data (5) 3D or 2D (6) season or diurnal (7) climate type. Papers which were associated with air pollution were excluded.

Results

In this section, an overview is given of interactions of Urban Heat Islands, vertical temperature lapse rates and tall buildings’ influence on urban wind flows. At the beginning, there were several thousands of papers about UHI in each database. After comparing and screening the literature search results (Table 2), based on an in-depth abstract selection, 13 unique studies from literature databases seem to be eligible and were further analyzed. Subsequently, results of additional studies and limitations are addressed.

Scoping search revealed there are thousands of papers on the topic of the Urban Heat Island. Within these, it was very difficult to find papers that answered the research question directly.

Step 1: Databases

Table 3 shows the results from the five search databases: ScienceDirect, Scopus, ProQuest, Engineering Village and SAGE journals. Three of the 13 studies showed information about temperature gradient which is not many but quite useful for understanding temperature differences in vertical direction.

Two studies mentioned difference temperature or wind speed between Urban Canopy and Urban Boundary Layer. In Pillai’s study, uniform height and non-uniform height buildings induced different urban canopy configurations were investigated by experimental and numerical simulation. Boundary layer height temperature above canopy was taken as the roof surface temperature, and the center point temperature of the canopy was chosen as the reference temperature for buildings surfaces(Subramania Pillai and Yoshie, 2012). The detailed relationships or differences between the temperature of urban canopy and boundary layer were not compared. In Li’ study, the typical winter urban boundary layer over Beijing was investigated(Li et al., 2005). The effects of variables on urban boundary layer structure were indicated in that paper, and the urban canopy layer was considered as a factor which could not give answer about the relationship or temperature difference between the boundary layer and urban canopy layer.

Table 2: Search results quantity from database(until 13 November 2016)

Database	**Search limitation**	**Quantity**	**Database**	**Search limitation**	**Quantity**
Science Direct	Urban heat island(title-abstr-key)	1091	Scopus	Urban heat island(title-abs-key)	3886
	Height or depth(title-abstr-key)	117		Height or depth(title-abs-key)	339
	Temperature(title-abstr-key)	80		Temperature(title-abs-key)	239
	Simulation(title-abstr-key)	25		Simulation(title-abs-key)	71
	Building(title-abstr-key)	17		Building(title-abs-key)	32
	wind(title-abstr-key)	5		Wind(title-abs-key)	11(duplicates 5)
	Research relevant (air quality exclude)	4		Research relevant (air quality exclude)	5
ProQuest	Urban heat island(anywhere except full text)	4017	Engineering Village	Urban heat island(subject/title/abstract)	2299
	Height or depth(anywhere except full text)	375		Height or depth(subject/title/abstract)	200
	Temperature(anywhere except full text)	258		Temperature(subject/title/abstract)	141
	Simulation(anywhere except full text)	64		Simulation(subject/title/abstract)	56
	Building(anywhere except full text)	17		Building(subject/title/abstract)	30
	Wind(anywhere)	6(duplicates 3)		Wind(subject/title/abstract)	9(duplicates 8)
	Research relevant (air quality exclude)	2		Research relevant	1
SAGE journals	Urban heat island(all fields)	2293			
	Height or depth(all fields)	1259			
	Temperature(all fields)	723			
	Simulation(abstract)	34			
	Building(abstract)	19			
	Wind(abstract)	3			
	Research relevant	1			

Building type was rarely pointed out in these studies expect three of them focused on study areas. It is not because study areas played a specific role in urban heat island studies, while maybe because study area is the most reachable area for authors as researchers.

All of these studies adopted numerical simulation methodology and a few of them also picked up measured data mainly for validation. Fluent was the most common numerical simulation software which was used in these studies. Then ENVI-met followed as second most popular simulation method. Most of these studies chose 3D as modeling, and only a few of them used 2D model. In the CFD simulation of Nazarian's study, a street-scale urban environment was investigated and the average temperature of all four walls of a building(Nazarian and Kleissl, 2015). According to this information, it is possible to get the temperature of building walls at different height through Fluent simulation. In addtion, mean air temperature at 1.5m height was got in Cao's study on Guangzhou city(Cao et al., 2015), which indicated air temperature at different height could also be obtained through Fluent.

6 of 7 papers which mentioned research season was about summer, while only one of them study winter which took air pollution into consideration as well.

Some of these studies gave the research location and others did not. The given locations included different climate types, but all of them are in dense areas.

When investigating height, some research investigate height-to-width ratio (Bourbia and Boucheriba, 2010; Oleson et al., 2008), or they investigate city area with same height different density(Stewart et al., 2014). 5 cases were studied which were concerned about H/W effect on the surrounding environment(P.J.C et al., 2015). In Pillai's study, uniform height buildings and mixed arranged non-uniform height buildings with different building coverage ratio were investigated(Subramania Pillai and Yoshie, 2012), but there are no studies working on UHI with indivadual high-rise building surrounded by uniformed low-rise buildings scenario.

Urban form and function as building performance parameters were studied(Mohammed A. and Jae D., 2015). 10 local climate zones with different city form, compact high-rise, mid-rise, low-rise and open high-rise, mid-rise, low-rise and so on, were estimated. These results addressed the building height definitely has influences on the UCI. But the model with the same height in one climate zone could not show the effect of one tall building on surrounding atmosphere. The model formulation is associated with surface emissivity, albedo, roughness length, building height, vegetation fraction, anthropogenic heat, initial boundary-layer height.

According to all of these parameters, the estimation was found from the calculation(Theeuwes et al., 2015). In Yupeng's study, three types of area, high-rise, middle-rise and detached house area, are investigated by software ENVI-met (Yupeng et al., 2015). It is possible to do the same simulation according to the detailed input parameters. And that make it possible to use the similar simulation method to investigate the building height effect on UHI. Additionally, 3 different building coverage ratio coupled with 2 categories, uniform height building and non-uniform height building, totally 6 city models

Table 3: Results of eligible studies(until 13 November 2016)

Study	Temperature Gradient	Difference between Urban Canopy and Urban Boundary Layer Temp / Wind	Type of building/ Office or Apartment	Measured or simulated data	3D or 2D	Season Day / Night	Climate Type/ Location	Conclusion
(Nazarian & Kleissl 2015)	Not reported	Not reported	Not reported	Numerical simulation :ANSYS/FLUENT	3D	Summer Diurnal	Southern California, USA	The ground and wall temperature increase with canopy height-to-width ratio. Land cover modification with urbanization, larger aspect ratio, and smaller reflectance from ground surface, all promote UHI.
(Cao et al. 2015)	Not reported	Not reported	Not reported	Numerical simulation: FLUENT	3D	Summer	Guangzhou zhujiang New Town, China	Roads and wind direction should be arranged in a specific angle to increase the wind speed and reduce temperature as roads provide the broad path for urban ventilation.
(Kong et al. 2016)	Vertical section of air temperature	Not reported	Study area	Numerical simulation: ENVI-met	3D	Summer	Nanjing, China	In the vertical direction, the effect of the removal of green spaces on near-surface wind field is rear; above the surface, there is significant increase on the turbulence perpendicular to the main wind direction.
(Subramania Pillai & Yoshie 2012)	Temperature contour	Temperature in urban canopy and boundary layer height	Not reported	Measured: wind tunnel Numerical simulation: FLUENT	3D	Not reported	Not reported	No matter for uniform or non-uniform building heights cases, the convective heat flux from canopy surfaces decreases with the increase of building cover ratio; the effects of building height variation are not remarkable.
(Park et al. 2013)	Not reported	Not reported	Not reported	Numerical simulation: Urban Micro-climate Management System	2D	Not reported	Not reported	Green urban regeneration improved the urban environment of wind and temperature at ground level with wind thickness increase and reduce the urban heat island as well as mitigate the energy consumption.
(Bozonnet et al. 2015)	Not reported	Not reported	Not reported	Measured: data acquired by LEEA laboratory Numerical simulation: ENVI-met, SOLENE-microclimate	3D	Summer	Not reported	From street to district scale design issues of UHI mitigation techniques are highlighted; at the urban scale large-scale modelling of physical processes are required for assessing UHI mitigation.
(Li et al. 2005)	Vertical cross-section of temperature	Thermal structure of Urban Boundary Layer	Not reported	Numerical simulation: MM5-CUP	2D	Daytime, night time winter	Beijing, China	Different extent urbanization experiment addresses that wind speed would decrease and turbulent kinetic energy increase with the increase in the density and height of buildings. At the same time, the bottom of nocturnal elevated inversion would increase in city area, and the intensity of urban heat island would strengthen.

Continued

Table 3: Continued

Study	Temperature Gradient	Difference between Urban Canopy and Urban Boundary Layer Temp / Wind	Type of building/ Office or Apartment	Measured or simulated data	3D or 2D	Season Day / Night	Climate Type/ Location	Conclusion
(Gutiérrez et al. 2015)	Not reported	Not reported	Not reported	Measured: Observations Numerical simulation: Weather Research Forecasting(WRF) model, Urban Canopy Model(UCM)	Not reported	summer	New York City, USA	In the most complex urban scheme, the temperature vertical profiles at the location of the highest building were characterized by steep lapse rate and the absence of an nocturnal elevated inversion.
(Holt & Pullen 2007)	Not reported	Not reported	Not reported	Numerical simulation: Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS)	2D	Daytime, night time summer	New York City, USA	Due to wall and road effects, Weather Research Forecasting-Urban Canopy Model better maintains UHI through increased nocturnal warming. For Brown and Williams Urban Canopy Model, urban wind speed decrease significantly, with daytime decrease generally over tallest building heights region. The surface layer warms much more during night than in the daytime with the depth increase of urban canopy.
(Qaid & Ossen 2015)	Vertical air temperature	Not reported	Not reported	Numerical simulation: ENVI-met	3D	Daytime, night time	Putrajaya Boukevard, Malaysia	Asymmetrical streets enhance more wind flow than low symmetrical streets and block more solar radiation, when tall buildings face wind direction or solar altitude.
(Memon et al. 2010)	Temperature contour	Not reported	Not reported	Numerical simulation: FLUENT	2D	Daytime, night time	Not reported	There is an air temperature difference between high and low aspect ratio street canyon, and the difference was highest during the night time. Meanwhile air temperature increased when ambient wind speed reduced.
(Rafieian et al. 2014)	Not reported	Not reported	Study area	Numerical simulation: ENVI-met	Not reported	Not reported	Tehran, Iran	A significant relationship exists between Sky View Factor and the intensity of Urban Heat.
(Zhang et al. 2012)	Not reported	Not reported	Study area	Numerical simulation: FLUENT	3D	Not reported	HongKong	A new building at the HK PolyU Campus under eight prevailing wind directions was modelled by CFD and the new building would change the environment which is more comfortable in winter with Velocity Ratio decrease and less uncomfortable in summer with Velocity Ratio increase.

were investigated. With the same building coverage ratio, the temperature contour of non-uniform height case was quite different from that of uniform height case. In this research, CFD was used to simulate and this method has been verified through comparing with experiment result(Sivaraja Subramania and Ryuichiro, 2012). Even the non-uniform height buildings are arranged regularly, not a high-rise building penetrating the UCL.

Step 2: Specific keywords

The initial search terms in the article title, abstract or keywords were: 'Urban Heat Island', 'height or depth', 'temperature', 'simulation', 'building' and 'wind' as each of them was an aspect of this study. Articles were most relevant to the research topic after searching these 6 terms. Apart from the papers containing all of the 6 terms, some of the others which only had 2, 3 or 4 terms were also explored.

First of all, "Lapse rate of temperature" and "in dense area" as two limitations were searched in Title-Abs-Key with different searching tools to figure out lapse rate profile in the dense area (Table 4).

Table 4: (until 26 October 2016)

Searching Tool	**Quantity**
ScienceDirect	5
Scopus	9(duplicates 3)
ProQuest	6(duplicates 4)
Engineering Village	3(duplicates 3)
SAGE journals	0

Secondly, UHI, rural, air temperature and height as four limitations were searched in Title-Abs-Key with different searching tools to investigate the height of UHI differences between urban and rural area (Table 5).

Table 5: (until 26 October 2016)

Searching Tool	**Quantity**
ScienceDirect	12
Scopus	10(duplicates 6)
ProQuest	19(duplicates 12)
Engineering Village	11(duplicates 8)
SAGE journals	0

Wind speeds increase in the boundary layer so that wind speed governing air leakage (infiltration) and surface heat loss is at the top twice that at the bottom.

If the environment is stable, the temperature of urban areas should be TU=TR+ ΔT, which TU is the temperature of urban, TR is the temperature of rural areas and ΔT is the UHI temperature difference. But what kind of temperature profile will be like when wind flow happened and the atmosphere is not stable? What will happen on the temperature contour of urban in vertical as well as in horizontal? To explore these questions, the next search limited to wind and lapse rate or temperature gradient in height.

Thirdly, Urban Heat Island, wind, temperature gradient and height as four limitations were searched in Title-Abs-Key with different searching tools to study temperature gradient of UHI taken wind into consideration(Table 6).

Table 6: (until 26 October 2016)

Searching Tool	**Quantity**
ScienceDirect	2(duplicates 2)
Scopus	3(duplicates 1)
ProQuest(all fields)	5(duplicates 4)
Engineering Village	5(duplicates 4)
SAGE journals	0

Finally, Urban Heat Island, wind and lapse rate as three limitations were searched in Title-Abs-Key with different searching tools as lapse rate had similar meaning with the temperature gradient in height(Table 7).

Table 7: (until 26 October 2016)

Searching Tool	**Quantity**
ScienceDirect	0
Scopus	5
ProQuest(all fields)	2(duplicates 1)
Engineering Village	2(duplicates 1)
SAGE journals	0

In Bornstein's study, when the average height of the base in urban elevated 310m, urban-rural temperature differences became zero(Bornstein, 1968). In S.Pal's study based on Paris, because of the effect of UHI, the mean nocturnal boundary layer depth over the urban area on average 74m(58%) higher than its adjacent suburban areas, and if exclude UHI effects, the number should be 63m(45%)(Pal et al., 2012). UBL height as one of the impact factor of UHI depends on the amount of surface energy. Because of the warming and heat storage, turbulent processes are induced above cities. Daily UBL gets unstable and its depth changes from daytime till night time(Aude and Valery, 2001). In Paris, daytime well-mixed convective boundary layer showed higher entrainment zone thickness(326m) over urban areas than over suburban(234m) and rural(200m) areas(Pal et al., 2012). In addition, it is confirmed that wind speed and lapse rate could assess the urban heat island intensity(Nkemdirim, 1980). In Giovanini's study, Trento of Italy as an extra urban was investigated, and the UHI intensity tends to be slightly stronger during dry months which influenced by seasonal lapse rate changes. Furthermore, stronger wind makes weaker UHI intensity(Giovannini et al., 2011).

Discussion

The analysis shows that urban heat island intensity is related to the city size which is measured by population(Oke, 1973). In Oke's later study, an empirical model simple incorporating wind speed and city size was proved to be able to describe urban heat island(Oke, 1976). And Padmanabhamurty made the relation of lapse rate and UHI as well as wind speed at 10m(Padmanabhamurty and Hirt, 1974). Besides, a significant heat island increases with the height-to-width ratio(Oleson et al., 2008), when a new tall building which is much taller than neighbor buildings will be built, the increase of height-to-width and the effects on urban heat island intensity around its surrounding area could be estimated. Simultaneously, air flow environment around the new building would be changed. As the importance of street canyon aspect ratio and wind speed on urban heating have been highlighted(Memon et al., 2010). In Stewart's study, urban and rural landscapes were divided into 17 standard classes, buildings intensity is relevant with urban heat island magnitude(Stewart et al., 2014).But the studies from the literature review focused more on the uniform or the non-uniform but regular arranged urban impact on UHI, rarely on individual building height.

Especially the scenario that individual tall building surrounded by low-rise buidings has not be investigated, like a high-rise building breaks through the urban canopy. What the lapse rate will be like above original urban canopy before the new large scale tower is placed is still a knowledge gap.

Currently, simulating energy consumption model of urban buildings need site-specific microclimate data. And site-specific weather data relies on calculation based on operational weather station from rural areas. Some relative models have been investigated, like Local-Scale Urban Meteorological Parameterization Scheme(LUMPS)(Grimmond and Oke, 2002) based on urban canopy model, the canyon air temperature(CAT) model a rural-to-urban weather transformation, as well as incorporating vertical diffusion model and urban boundary layer model(VDM-UBL)(Bueno et al., 2012). The urban weather generator is composed of four coupled modules: the rural station model(RSM); the vertical diffusion model(VDM), the urban boundary layer(UBL) model and the urban canopy and building energy model(UC-BEM)(Bueno et al., 2013). And it could be used alone or integrated into existing programs(Bueno et al., 2013). According to the literature review, Fluent, ENVI-met as well as UWG did well in its own simulation scenario.When UHI, lapse rate and wind speed as parameters impacting natural ventilation of a case study office building surrounded by a complex set of urban buildings were explored, energy consumption would be put into consideration as well. And whether or not the data from the three software Fluent, ENVI-met as well as UWG could be exported into EnergyPlus or similar energy simulation software needs to be explored in next practical stage.

Conclusion

In this study, relevant papers have been reviewed and try to answer the research question about the building height influence on its surrounding microclimate. Currently, no study worked on the interaction of UHI, wind speed and lapse rates in dense urban areas and the microclimate of individual new tall building surround by low-rise buildings. The paper documents the influence of temperature lapse rates in dense urban areas. The temperature lapse rates profile in urban areas differ from that in rural areas. It quantifies the influence of wind speed on likely urban heat island intensity. It could be concluded that UHI affects lapse rate in urban areas and lapse rate reflects UHI intensity. Individual high-rise building changed its surrounding microclimate especially air flow state. Rising wind speed may induce temperature as a result UHI intensity decreased. At the same time, temperature lapse rates profile changed. Relationship of every two of these three parameters could be addressed according to previous studies but there still a knowledge gap on the impact of all these three parameters which could be a loop. Moreover, the measured and variable simulated methodology were compared and investigated. So in the future simulation study, the concrete influence of building height on its microclimate will be simulated and take lapse rate, wind speed as well as UHI into consideration.

Finally, the potential for openable windows to provide sufficient natural ventilation for summer cooling could be estimated according to the future simulation analysis.

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