# Applicability of Overhangs for Energy Saving in Existing High-Rise Housing in Different Climates

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***Abstract*—**Upgrading the thermal performance of building envelope of existing residential buildings is an effective way to reduce heat gain or heat loss. Overhang device is a common solution for building envelope improvement as it can cut down solar heat gain and thereby can reduce the energy used for space cooling in summer time. Despite that, overhang can increase the demand for indoor heating in winter due to its function of lowering the solar heat gain. Obviously, overhang has different impacts on energy use in different climatic zones which have different energy demand. To evaluate the impact of overhang device on building energy performance under different climates of China, an energy analysis model is built up in a computer-based simulation program known as DesignBuilder based on the data of a typical high-rise residential building. The energy simulation results show that single overhang is able to cut down around 5% of the energy consumption of the case building in the stand-alone situation or about 2% when the building is surrounded by other buildings in regions which predominantly rely on space cooling though it has no contribution to energy reduction in cold region. In regions with cold summer and cold winter, adding overhang over windows can cut down around 4% and 1.8% energy use with and without adjoining buildings, respectively. The results indicate that overhang might not an effective shading device to reduce the energy consumption in the mixed climate or cold regions.

***Keywords*—**Overhang, energy analysis, computer-based simulation, high-rise residential building, mutual shading, climate.

## I. Introduction

THE energy use of existing buildings accounts for 40% of the total energy consumption in most developed countries, and the dwelling sector is expected to take up 67% of the world's energy by 2030 [1]. In modern societies, a significant proportion of energy use in domestic buildings is attributed to heating ventilation and air conditioning (HVAC) and this is particularly the case in hot climate regions. Minimizing the heat gain through the envelope of building in hot regions would reduce the reliance on HVAC and hence would help conserve energy. Research studies have indicated that window overhang can reduce the energy consumption by over 40% in hot climate countries [2] making it a popular solution for sustainable retrofit [1]-[5].

A comparison between the vertical side-fin and overhang has demonstrated that the latter is a more effective shading device to reduce the incident of solar energy [6]. Yet, the energy saving performance of overhang may vary under different climatic conditions. For instance, overhang can result in a 5.3% reduction in energy use in hot and humid condition of Hong Kong [7]. A study in Singapore, however, points to a 40% reduction in solar heat gain by installing overhang installed on the eastern orientation facades of buildings [8]. In arid and hot Tehran of Iran, installing overhang over single clear glass window is reported to be more effective than double glazed windows in terms of energy conservation [9]. Another study in Shiraz of Iran has shown that overhang can reduce the cooling load by 12.7% during summer [10]. In Saudi Arabia, a 1.5 m overhang can decrease the solar heat gain of occupied areas by more than 40% [11]. In South Korea, overhang can cut down nearly 18% [12] to 20% of cooling load in summer [13]. In Arizona of the USA, overhang when used in conjunction with side fins is found to be an effective measure to reduce direct solar heat gain as confirmed by a drop in the window glass surface temperatures [14]. In Houston of the USA, overhang of 0.85 m projection can decrease about 10% of the annual energy use for buildings with large-area windows [15].

A study in Italy shows that the energy reduction due to the installation of overhang is around 20% in the warmest regions of Italy while it is less than 10% in the cold zones [16] as overhang does not only stop unwanted solar heat gain in summer, but it would also block the incident solar radiation in winter [17].

In cold regions like Chicago, the energy reduction produced by overhang is compromised by almost a half [15]. It is obvious that overhang is helpful to decrease the heat from entering a building through the windows in different seasons [18]. Since overhang reduces the solar heat gain in winter, it would inevitably increase the heating load in winter for cold regions which reaffirms that the effect of overhang is influenced by the different climates [14].

The projections of overhang and overshadowing are the key factors influencing the thermal performance of overhang. Unfortunately, most studies have not duly considered the mutual effect of surrounding premises. In order to unveil the effect of overhang on the thermal performance of high-rise buildings, this study examines the energy consumption of a typical high-rise residential building in a stand-alone situation as well as in built-up areas surrounded by buildings. The study models the energy savings due to the installation of overhang on the reference building with and without the mutual shading effect of adjoining buildings. In order to unveil the energy saving performance of overhang in various climate zones, three different climatic conditions were considered when analyzing the performance of overhang. According to previous study, the projections of 0.5 m, 1.0 m, and 1.5 m were chosen for the

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analysis [16].

## II. Methodology

To quantify the energy reduction performance of overhang, the annual energy consumptions for heating and cooling were calculated under various climatic conditions in China. In this study, a computer simulation program known as DesignBuilder was used, and the simulation was based on a typical high-rise residential building in China. To increase the accuracy, the simulation was based on the climate of three different climatic zones in China, i.e. (i) cold area; (ii) hot summer and cold winter region; and (iii) hot zone.

The research steps involve the: (i) selection of appropriate simulation tool for the assessment of the thermal performance; (ii) identification of the climatic features of the cities in the three selected climatic zones of China; (iii) analysis of the characteristics of the case building and its surrounding environment; (iv) prediction of the annual cooling and heating consumption of the case building as compared to that of the building fitted with overhang in a stand-alone situation as well as within a building network; (v) conducting data analysis according to the energy simulation results of 1.0 m overhang projection, mutual shading, and different climatic conditions; and (vi) review the energy-saving impacts of overhang in different climates with or without mutual shading.

## III. Computer-Based Simulation Program

DesignBuilder is a popular building performance simulation tool as it can display a graphical 3D energy model [19]. The two essential features of building simulation tools are the availability of intelligent design knowledge-base and user friendliness [20], [21]. In DesignBuilder, a powerful database and various modeling capabilities are available to evaluate the energy performance of buildings [22]. It also provides a series of templates to cover various types of building parameters, and users can simply select the most appropriate parameters for energy analysis [23]. DesignBuilder is based on the engine of the latest EnergyPlus which was widely regarded as the most comprehensive one [24], [25]. The reliability and simulation accuracy of DesignBuilder have been validated by Building Energy Simulation TEST (BESTest) [26].

## IV. Climatic Conditions in Typical Cities with High Density Population

In China, a large proportion of the population lives in the eastern part of the country as it is the place where those major cities are located. The three chosen climate regions, i.e. cold or hot summer, cold winter, and hot zones, cover more than one-third of the population in the territory [27].

Hong Kong is located in the hot climate with the high-dense high-rise buildings. The average population density is up to 6,544 habitants/km$^2$ with lots of tall buildings within a tiny spatial proximity due to a huge demand for accommodation [28]-[30]. More than 90% of the total population live in high-rise buildings and also over 90% of existing residential apartments are in the form of high-rise buildings [31]. The mean maximum temperature in summer is 31-34 °C from April to October, while the outdoor environment is quite mild in winter. In hot seasons, the humidity of Hong Kong can go up to 80% and air conditioning is in great demand to maintain the indoor comfort. The annual sunshine ratio is more than 42%, and the sunshine condition decides the necessity to reduce the solar heat gain through windows. Owing to the dominance of a hot and humid climate and the increasing requirements of indoor comfort, air conditioning has assumed the largest proportion of energy consumption in the residential sector of Hong Kong [32]. There is seldom any space heating demand due to its relatively mild winters.

Shanghai is the largest megacity in China and its population density is amongst the highest in mainland China. The high-rise housing ratio has a positive correlation with the population density in this city [27]. Existing high-rise apartment buildings account for about 44% of the total residential blocks in the area [33]. To meet the accommodation requirement, thousands of high rise buildings have been built up and they are densely packed on small areas [34]. Being a seasonal city, the hot summer continues for about 4 months from June to September but its winter is just from December to February. The maximum temperature of Shanghai is around 32 °C in hottest months but in coldest seasons, the mean minimum temperature can be as low as 3 °C. Based on the weather condition, cooling in summer and heating in winter are both in great demand to maintain a comfortable indoor environment.

Beijing is the biggest city in cold climatic zone. The developed land area is 16,807 km$^2$ and the highest population in the Xicheng District in the urban area of Beijing with a density of over 25,000 persons/km$^2$. To make a good use of land, high-rise buildings have been built, and they make up about 78% of the existing buildings in urban area [35]. These high-rise housings have been overdeveloped since 1990s [36]. Beijing has typical warm temperate semi-humid continental monsoon temperatures with very distinct four seasons [37], [38]. The monthly daily average temperature in the coldest month is about -3.7 °C while in hottest month it is around 26 °C. The cold winter usually lasts for five months from November to March but the period of summer is much shorter from June to August. The weather condition points to a more significant heating demand while the cooling requirement would just account for a relatively small proportion of the total energy consumption of dwellings in Beijing.

## V. Characteristics of Case Building

The case building is an existing high-rise residential building that has been built up for more than 20 years. It is a public housing with typical layout. Insulation was not a common consideration for buildings of similar age in Hong Kong, Shanghai and Beijing, while the construction materials being used in these three regions are quite similar to each other [39], [40]. The major structure of exterior wall is mosaic tile (5 mm), cement plaster (30 mm), concrete block (200 mm) with cement plaster (30 mm) from outer side to inner side. The roof construction is more complicated and there are several layers of materials with the outermost and innermost material being clay tile (10 mm) and cement plaster (20 mm). Meanwhile, the functional components include the polyurethane foam (50 mm), bitumen sheet (1 mm) and the reinforced concrete (150 mm) from the top to the bottom layers. The window glazing employs 6 mm single clear glass and its thermal property is not helpful to reduce the solar heat gain in summer and stop the heat transmission in winter. Its solar heat gain coefficient (SHGC) is 0.819, and U-value is 5.78 W/m$^2$·k. It did not take shading devices into account when the building was designed and constructed.

TABLE I
BUILDING CHARACTERISTICS

| Component | U-value (W/m$^2$·k) | Materials and layers |
|---|---|---|
| Exterior wall | 1.868 | o 5 mm mosaic tile (outermost layer)<br>o 30 mm cement plaster<br>o 200 mm concrete block<br>o 30 mm cement plaster(innermost layer) |
| Interior wall | 1.942 | o 20 mm cement plaster<br>o 150 mm concrete block<br>o 20 mm cement plaster (innermost layer) |
| Roof | 0.471 | o 10 mm clay tile<br>o 30 mm cement plaster<br>o 50 mm polyurethane foam<br>o 1 mm bitumen sheet<br>o 10 mm cement plaster<br>o 150 mm reinforced concrete<br>o 20 mm cement plaster |
| Standard floor | 2.470 | o 10 mm cement plaster<br>o 20 mm reinforced concrete<br>o 10 mm cement plaster |
| Door | 2.498 | o wooden flush panel hollow core door<br>o plywood panel<br>o air gap<br>o plywood panel |
| Window (SHGC= 0.819) | 5.78 | o 6 mm single generic clear glass pane:<br>o aluminum window frame;<br>o main Window height: 1500 mm<br>o main sill height: 900 mm<br>o main window width: 1200, 1500, 1800 or 2100 mm |

The configuration of typical floor is made of reinforced concrete and cement plaster as described in Table I and their U-values are about 2.470 W/m$^2$·k. The interior wall is composed of cement plaster (20 mm), and concrete block (150 mm) with cement plaster (20 mm). Their U-values are 1.868 W/m$^2$·k and 1.942 W/m$^2$·k, respectively. The door consists of wooden flush panel with hollow cores, and its U-value is 2.498 W/m$^2$·k. Materials on the roof are useful to reduce the heat transmission, and the whole U-value is 0.471 W/m$^2$·k which is far less than that of floor.

Based on the published information, the common occupancy density is about 0.01 people/m$^2$ in high-rise public housing in Hong Kong [41]. The air conditioner is usually turned on in the afternoon, evening and night for the elderly family members who stay at home and children after they return home after schools. Its service period is from 1:00 pm to 7:00 am the next morning [42], [43]. In the reference building, the window mounted air conditioner is used for the space conditioning and its working period spans from April to October for cooling in Hong Kong. To meet the indoor thermal comfort, the set point of air conditioning is at 24 °C in Hong Kong [44]. There is almost no space heating demand and most air conditioners in the housing flats have no capacity for heating. The annual sunshine ratio is more than 42% and the sunshine condition decides the necessity to reduce the solar heat gain through windows [45]. Due to the dominance of a hot and humid climate and the increasing requirements of indoor comfort, air conditioning consumes a larger proportion of total energy consumption in the residential sector of Hong Kong compared to other domestic equipment [32]. The related inputs for the heating and cooling are shown in Table II.

TABLE II
OPERATION PARAMETERS OF AIR CONDITIONER

| | Heating | Cooling |
|---|---|---|
| Equipment | unitary air conditioner | unitary air conditioner |
| Temperature set point | 20 °C | 24 °C |
| Operation schedule | 24 hours during heating months:<br>o Hong Kong – no heating need for<br>o Beijing – November to March<br>o Shanghai – December to February | 1:00 pm –7:00 am during cooling months:<br>o Hong Kong – April to October<br>o Beijing – June to August<br>o Shanghai - June to September |

There are neighboring buildings surrounding the typical building in all directions. The aspect ratio (H/W), i.e. building height-to-width between buildings ratio, is a direct parameter to reflect the density of high-rise buildings and the thermal environment of the reference building. It has a close relationship with the mutual shading effect of adjacent buildings [46]. The aspect ratio (H/W) of the typical building is larger than 2.0 on each direction, and this study assumes that the canyon H/W ratio is 2.0 for the case building's thermal environment in order to simplify and simulate the mutual shading effect of adjacent buildings. The configuration of neighboring canyon space was hypothetically modified to build up an energy model in DesignBuilder. The same H/W and adjacent buildings are beneficial to model the outdoor thermal environment and there is no barrier to indicate the mutual shading effect on the energy consumption of the typical building. After modeling the nearby space, the study focuses on the thermal performance of upgrading the case building with and without mutual shading in term of its energy consumption for both heating and cooling.

## VI. RESULTS AND DISCUSSIONS

Several parameters have been adjusted for the reference building in order to quantify the energy savings achieved by the overhang with and without mutual shading effect under the three types of climates. Rounds of energy simulations were performed for the three selected cities, i.e. Hong Kong, Shanghai and Beijing, based on different projections of overhang installed on the building under the stand-alone situation and when the same building in located in a dense urban context.

### *A. Effect of Overhang in a Stand-Alone Building*

When evaluating the cooling demand of the stand-alone building in Hong Kong, the longest projection 1.5 m of overhangs can produce the largest energy saving of 5% as displayed in Fig. 1. Despite that, the 1.0 m overhang also can lead to a 4.25% energy reduction. It means that increasing the projection of overhang is not particularly useful to reduce the energy consumption when it reaches a certain level.

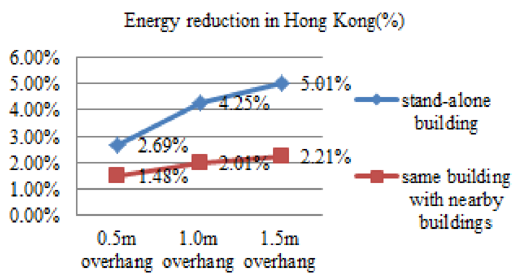


Fig. 1 Energy reduction caused by overhangs in stand-alone building and the same building with nearby buildings in Hong Kong

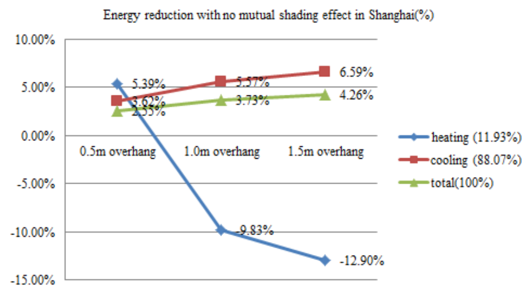


Fig. 2 Energy reduction caused by overhangs in stand-alone building in Shanghai

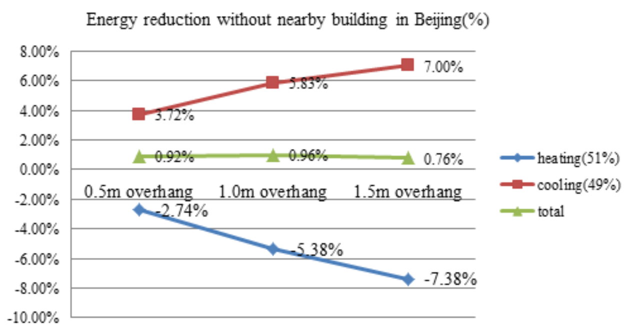


Fig. 3 Energy reduction caused by overhangs in stand-alone building in Beijing

According to the simulation and calculation result in in Shanghai as shown in Fig. 2, it is obvious that overhang is beneficial to reduce the cooling load but it leads to an increase of heating demand. The reduction in demand for cooling is as much as 6.59% while the demand for heating is increased by 12.9% in the stand-alone building scenario. Owing to the bigger proportion (88.07%) of the cooling consumption in the studied energy use, the overall energy saving achieved by the most effective overhang is about 4%. It depicts that the energy-saving of overhang in this climate is similar that in Hong Kong with hot climate. The most appropriate length of overhang is still 1.0 m.

In Beijing, overhang helps the case building reducing the energy consumption for cooling by about 7% as illustrated in Fig. 3. However, it makes a great contribution to increase the heating demand as it reduces the solar heat gain. The increase is up to 7.38% as well. The positive effect and negative impact of overhang have cancelled each other out and hence the overall energy saving is less than 1% in this cold area. This result shows that overhang is not an effective solution for retrofitting existing buildings in the heating-dominant climate.

Comparing the most effective overhang of the three climate zones, it was found that overhang can be regarded as an effective retrofit measure in hot region as well as hot summer and cold winter region when the building in not affected by overshadowing. However, its effectiveness in energy saving is much diminished for buildings under cold climatic conditions.

### *B. Effect of Overhang When the Building Is Surrounded by Other Buildings*

In order to accurately quantify the effect of mutual shading effect, the simulation assumed that the height of adjoining buildings and the distance between the case building and its surrounding buildings on four directions are same as each other. Under the mutual shading environment, the effects of overhang on building thermal performance are very different the same stand-alone building. The simulated energy consumption shows that the energy savings produced by overhang can be counteracted by the mutual shading of adjacent buildings.

As shown in Fig. 1, the largest energy reduction is achieved by the 1.5 m overhang with around 2% of energy saving in the case of Hong Kong. The mutual shading effect reduces the contribution of overhangs to energy conservation. It can be noted that the overhang cannot reduce a great amount of energy consumption in dense high-rise buildings environment due to the mutual shading effect in the cooling dominant climate.

In Shanghai with the cooling and heating demands of 88.07% and 11.93% respectively, overhang helps to reduce the energy consumption for cooling but it is not helpful in reducing the heating load. When there are some nearby buildings surrounding the examined building, the biggest reduction of cooling demand is only at 2.8% compared to the baseline case (Fig. 4). The heating increase is not as dramatic as that in the stand-alone building and it is just one-third of the same parameter in the single reference building. This is because the overshadowing of surrounding building weakens the effect of the overhang.

In Beijing, both the heating demand and cooling demands are the predominant sources of energy use. Compared to the stand-alone situation mentioned above, the effect of overhangs in the same building with nearby buildings can be weakened by above 50%. It can be seen in Fig. 5 that the cooling reduction is about 3% which is less than half of that in the stand-alone control building. The heating increase is limited to below 2% which is not as significant as that in the single examined case building without mutual shading effect. The overall effect of overhangs in Beijing is less than 1% after considering the overshadowing of adjoining high-rise buildings in dense urban areas. In this kind of climate, overhang is not effective to help buildings reduce energy consumption in a real urban context. It is unreasonable to apply overhang as an energy-efficient retrofit solution in the cold climates under a dense urban morphology.

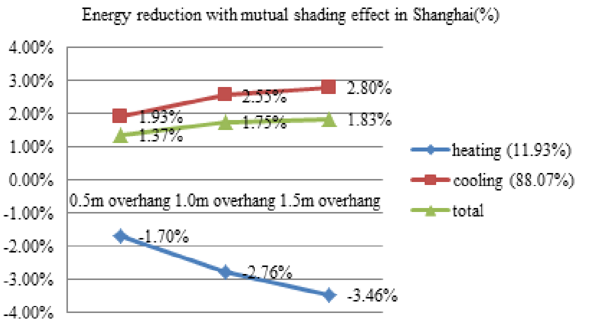


Fig. 4 Energy reduction caused by overhangs in the same building with mutual shading effect in Shanghai

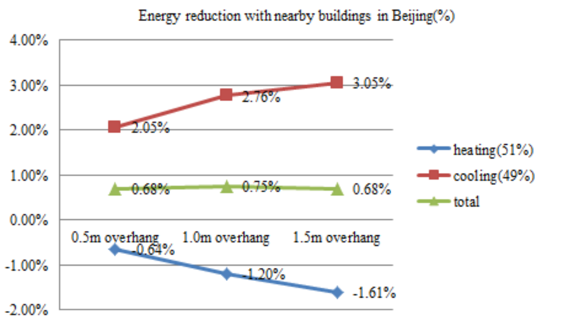


Fig. 5 Energy reduction caused by overhangs in the same building with mutual shading effect in Beijing

*C. Mutual Shading Effect on the Thermal Performance of Overhang*

It is obvious that the inter-building effect plays an important role in determining the building thermal performance. In Hong Kong, the mutual shading effect offsets above 50% of energy reduction achieved by overhang as revealed in Fig. 1. The overshadowing of nearby buildings on the case building can reduce the solar heat gain in summer and it is beneficial to cut down the cooling demand. The major contribution of overhang is to reduce the energy use for cooling requirement, and hence this retrofit measure has a knock-on impact on building thermal performance. Therefore, the effect of overhangs on the energy consumption of the reference building is not as expected when considering its practical surrounding environment.

In Shanghai, the knock-on effect is more significant. The overall energy saving caused by the same overhang in the case building with nearby high-rise buildings is far less than that in the same stand-alone building. The reduction ratio is above 4% in the single examined building but it drops to 1.8% when mutual shading effect is taken into account as shown in Fig. 6. The comparison presents that the overshadowing can reduce the energy saving of overhangs by 50%.

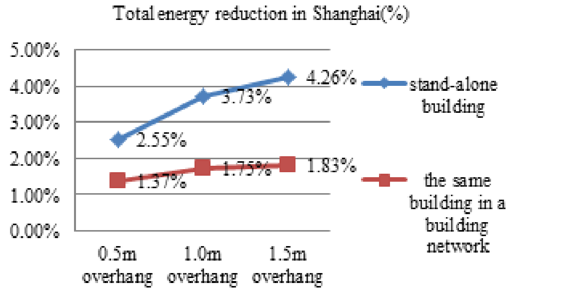


Fig. 6 Total energy reduction caused by overhangs in the stand-alone reference building and the same building in a building network

In Beijing, there is a totally different situation about the relationship between the effect of overhang and mutual shading. Due to the similar quantity of heating and cooling demands, the reduction of cooling is basically equivalent to the increase of heating when adopting overhang for the case building retrofit. This counterbalancing effect can defeat the purpose of overhang in this climate. Therefore, the overall energy reduction generated by overhangs is less than 1% no matter the examined building is a stand-alone one or placed in a building network with mutual shading effect as depicted in Fig. 7. This figure reveals that overhang is not effective in reducing the energy consumption in cold climate and it is unwise to employ it for the building retrofit in this region.

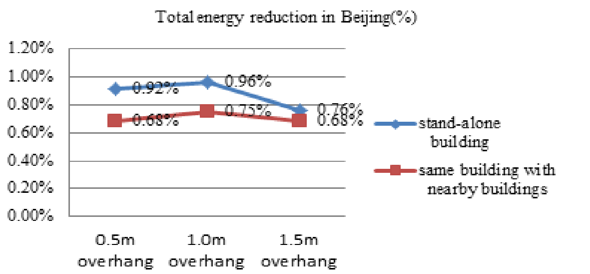


Fig. 7 Total energy reduction in the stand-alone reference building and the same building in a building network

## VII. Conclusion

This paper analyzes the effect of overhangs on the energy demand of a typical high-rise building in three climates of hot, hot summer and cold winter, and cold zones. The building thermal performance of the examined building with and without overhangs in different climates was calculated using a computer-based simulation tool – DesignBuilder.

The simulation results of the stand-alone building reveals that overhang can reduce the cooling demand by around 5% at hot climate regions and decrease the overall energy use for heating and cooling by up to 4.26% in a mixed climatic condition. But, for cold regions, overhang is not effective in reducing the total energy consumption of heating and cooling as it can increase the heating requirement dramatically. It is not reasonable to apply overhang to existing high-rise building to improve their energy efficiency in the cold climate.

The simulation results have also confirmed that that overshadowing of adjacent buildings can reduce the effectiveness of overhang by 50% in all of three climates. This significant effect indicates that it is essential to consider the overshadowing among high-rise buildings while evaluating their thermal performance. Ignoring the mutual shading effect of adjoining can result in an inaccurate prediction of energy consumption and misestimate the thermal performance of overhangs in various climates. This misleading prediction is harmful to select the most effective and energy-efficient shading devices for building retrofit.

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