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学位論文題目	Research on the Influence of Piloti Ratio on Outdoor Thermal Environment of Residential Blocks in Humid Subtropical Climate City （亜熱帯蒸暑気候下の住宅団地のピロティが屋外温熱環境に及ぼす影響の研究 ）
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論 文 内 容 要 旨

1 Introduction

The rapid urban development has led to many problems in cities, and these problems have been gained more and more attentions due to their influences on people's healthy, thermal comfort and environment and resource degradation all of the world. Global Warming and Urban Heat Island (UHI) have become major issues all of the world, and the environmental degradation results in not only the increase of energy consumption in cities but also healthy problem of people.

The subtropics are the geographical and climatic zone of the earth immediately north and south of the tropical zone, which is bounded by the Tropic of Cancer and the Tropic of Capricorn, at latitudes 23.5°N and 23.5°S and according to Troll-Paffen climate classification, it generally exists a large subtropical zone. The term "subtropical" describes the climatic region found adjacent to the tropics, usually between 23.5 and 40 degrees of latitude in both hemispheres. According to Köppen climate classification there are 4 kinds of typical subtropical climates, which are the Subtropical highland variety (Cwb), Mediterranean climate, Humid subtropical climate and Subtropical semi-desert/desert climate, and the summer climate in humid subtropical climate cities is always super hot. Therefore, piloti is commonly adopted in urban design, avoiding solar radiations and improving outdoor ventilations in humid subtropical cities (like Guangzhou in China, for example) and tropical climate countries (Malaysia, for example).

In recent years, many ways are adopted and integrated on improving the outdoor thermal environment, for instance, plant, high reflective capability materials of building envelope, green building walls and roofs, improvement of city ventilation, use of sea wind and decrease of artificial heat, etc. Many researches regarding to outdoor environment are carried out, such as field measurement, simulation and wind tunnel experiment, etc. In recent years, accompanying with the development of simulation techniques, many researches regarding to simulation combined with wind velocity, air temperature, humidity and radiation were carried out.

However, there is nobody who researched on the comprehensive influence of piloti on outdoor thermal environment. Li Qiong (south China University) researched on the relationship between piloti arrangement and velocity ratio, but this research did not consider lateral boundary influence and no thermal comfort index was included. Zhou Zeng (Huangzhong University of Science and Technology) researched on the velocity ratio by one building changing place in building block and changing piloti place in this standard building, but this research did not consider couple simulation method and no thermal comfort index was included. Also, the dynamic character of residential blocks and pilot was not researched by these 2 researches.

This research aims at researching on the comprehensive influence of piloti ratio on outdoor thermal environment (wind velocity, temperature, MRT) in humid subtropical climate cities and the influence of piloti ratio on integrated thermal comfort index (SET*) in humid subtropical climate cities, thus offering reference for residential building blocks design in humid subtropical climate cities.

2 Structure of this paper

In chapter 1, the introduction of research background (global warming and urban heat island), subtropical climate zones and characteristics of 4 typical subtropical climates, relative researches, the objective and structure of this study and research flow chart are given.

In chapter 2, review of prediction methodology on outdoor thermal environment and thermal comfort models are introduced.

In chapter 3, the results of a questionnaire survey which was carried out in Guangzhou, a typical humid subtropical climate city in China are introduced, and the subjective response to outdoor thermal environment of people of humid subtropical climate cities is researched.

In chapter 4, the dynamic outdoor thermal environment and thermal comfort of building blocks, piloti and human built elements were studied via a field measurement carried out in Guangzhou, China, and the dynamic characters of outdoor thermal environment of building blocks and piloti in humid subtropical climate cities were obtained by this field measurement.

In chapter 5, the comprehensive influence of piloti ratio on the outdoor thermal environment was researched by computational fluid dynamics simulation and the subjective response (result of Chapter 3) and ASHRAE standard were used to offer design references for architectures and designers.

In chapter 6, integrated with the dynamic thermal environment of field measurement and comprehensive influence of piloti ratio on outdoor thermal environment, conclusions and prospects of this study are given.

3 Conclusions and prospects

(1) The subjective response to outdoor thermal environment was studied via a questionnaire survey in Guangzhou, a typical humid subtropical climate city in China, and the acceptable rate (thermal sensation rate is less than 1.5) under different SET* intervals is obtained. When SET* is lower than 30 °C, the acceptable rate is expected to be 100%, and when SET* is between 30°C and 32 °C, the acceptable rate is expected to be 78%, and when SET* is between 32°C and 34°C, the acceptable rate is expected to be 65%, and when SET* is over 35 °C, the acceptable rate is expected to be lower than 30% (Table 1).

Table 9 acceptable rate of outdoor thermal environment during different SET* intervals

SET* range	SET*≤30°C	30°C < SET* ≤32°C	32°C < SET*≤34°C	SET* > 35°C
Acceptable rate	100%	78%	65%	< 30%

(2) In the piloti centralized situation, piloti can highly increase the wind velocity of those weak wind area, especially when piloti ratio equals to 100 percent, no weak wind area exists anymore, the minimum velocity is 0.9m/s and the highest wind velocity reaches 2.1m/s. The MRT of non-piloti area decreased with the increase of piloti ratio, especially when piloti reaches 100 percent, the MRT of non-piloti ratio area decreases faster, both of which should be due to the decrease of wall areas. Thus the SET* of non-piloti area is highly optimized when piloti ratio equals to 100 percent.

In the piloti centralized situation, piloti can highly increase the wind velocity under piloti, but when piloti ratio is 40 percent, the wind velocity under piloti is very low, leading to very bad outdoor thermal thermal environment under piloti. The MRT under piloti increased with the increase of piloti ratio, especially when piloti ratio equals to 100 percent, MRT increases faster, both of which should be due to the decrease of wall areas, leading to more short wave reflections, and when piloti ratio reaches 100 percent, the SET* under piloti is highly decreased.

The average SET*, area percentage of tolerance SET*, and the area of acceptable rate equals to 65% under different piloti ratios in a centralized situation is shown in Table 2, for those piloti flexible arrangement cased, this study shows that wind is highly influenced by piloti arrangement, so in this situation, a case to case study is necessary.

Table 2 The relationship between SET* and piloti ratio of piloti centralized residential building blocks

Piloti Ratio	Location	Average SET* (° C)	Area percentage of tolerance SET* (SET*<40)	Area percentage of acceptable rate equals to 65% (SET*<34)
0%	Non-Piloti	39.82	60%	0%
40%	Non-Piloti	39.63	65%	0%
	Under Piloti	41.73	0%	0%
60%	Non-Piloti	39.36	75%	0%
	Under Piloti	39.78	60%	0%
80%	Non-Piloti	38.71	85%	0%
	Under Piloti	38.13	100%	0%
100%	Non-Piloti	35.68	100%	10%
	Under Piloti	34.50	100%	40%

(3) The coupled simulation shows that wind is very important to create well-being outdoor thermal environment, for example, for the 40 percent piloti centralized case, the SET* is still very high even under the piloti which is because the low wind. The field measurement shows that the MRT under piloti and around building blocks decreased very slow after the peak value, which is due to the low sky view factors of piloti and around building blocks, so if the wind is very low, the outdoor thermal environment under piloti and around building blocks will be constantly crucial. This study shows that high piloti ratio can highly optimize the outdoor environment of both of piloti area and non-piloti area of residential blocks in the hottest time period, which is meaningful for optimizing the outdoor thermal environment in a dynamic way in humid subtropical climate cities.

(4) This is the first study which researches on the comprehensive outdoor thermal environment by piloti, and the research on the influence of piloti on outdoor thermal comfort is just the beginning. The prospects of this study are as follows:

a) The influence of piloti locations The location of piloti in each building is expected to get different result, as shown in this study, it does exist a weak wind area and strong wind area when piloti ratio equals to 0 percent, if the piloti locates in the weak wind edge, different result is expected to be get under same piloti ratio

b) Integrated with other construction technical and economic indexes Tetsu Kubota et al. proved there strong relationship between building coverage ratio and building height, and in this study, the clear relationship is found due piloti ratio by piloti centralized cases. This study should be developed by integrated with other construction technical economic indexes, for instance, building coverage ratio and building height. The final output of these developed researches is expected to be the relationship of outdoor thermal environment and these construction technical and economic indexes, offering references for architectures and urban planners. Floor area ratio is simple relationship with building coverage ratio, building height and piloti ratio, if the relationship between floor ratio and outdoor thermal comfort could be get, this is also a good reference for the construction companies to balance environment and cost.

c) Integrated with other way of improving the outdoor thermal environment There are many ways to improve the outdoor thermal environment, for instance, water surface ground, grass ground, green walls, trees and shading design. The influence of piloti should be integrated with these methods to create well-being outdoor thermal environment.

d) The influence of piloti under different climate cities and seasons This study focus on the humid subtropical city, because the outdoor thermal environment is very hot in humid subtropical climate cities, but the influence of piloti on outdoor thermal environment in different climate cities is also meaningful for architectures and urban planners when they design buildings in different climate cities. Also the influence of piloti at different season is also blank field. This study shows that piloti optimized the outdoor thermal environment in summer in humid subtropical climate cities, but in winter, poloti may lead to negative influence, but this can be decrease by shelter arrangement, which is also an interesting topic to be digged in the future.

論文審査結果の要旨

中国南部や香港、台湾をはじめとする亜熱帯蒸暑気候下のアジアの諸地域における都市化の進行は著しいものがあり、これに伴うヒートアイランド現象の進行により、屋外空間の暑熱化や冷房用エネルギー消費の増大が大きな問題となっている。このような蒸暑地域では、日射遮蔽や雨除け、あるいは風の通り道の確保等の目的でピロティのような半屋外空間が設けられることが多く、これら半屋外空間内部の環境については、従来より研究がなされてきた。一方、ピロティ設置による開口率の増加や日射遮蔽効果は建物周辺の気流分布や放射環境にも少なからぬ影響を及ぼすと考えられるが、その効果を詳細に分析した例はほとんどない。これに対して、本論は建物外部のミクロスケールの気候を制御するための要素としてピロティを位置づけ、ピロティが屋外の温熱環境に及ぼす影響を野外観測、温冷感に関する被験者アンケート、市街地空間の3次元放射解析と3次元流体解析により定量的に評価し、これを適切に配置して厳しい夏季の暑熱環境を緩和する方法を検討したものである。

まず本論文では、中国の広州市の華南理工大学の構内において、ピロティ内部、日向の広場、樹木下、池の岸辺等の様々な条件下で温熱環境測定と被験者アンケートを実施し、測定結果から算出した温熱環境指標SET＊（Standard Effective Temperature）とアンケートから得られた温冷感申告値の関係から、SET＊の値とその環境を“許容できる”と考える被験者の割合（acceptable rate）の関係を分析している。そして、SET*が30℃以下ではacceptable rateが100%となり、SET＊の増加に伴いその値が減少し、SET＊が34℃では65％まで、また35℃では30％まで低下するという結論を得ている。続いて、1階の床面積占めるピロティ面積の割合（ピロティ率）とピロティの配置の仕方をパラメータとして、これらの変化がピロティ内部と建物周辺の歩行者空間に及ぼす影響を、3次元放射・流体連成解析により系統的に分析し、市街地の風通しの改善と放射環境の改善の両面から詳しく分析している。そして、ピロティ率の増加に伴う建物外壁面積の減少により建物外壁面から周辺の歩行者空間に射出される長波長放射量が減少し、これにより屋外の歩行者空間の平均放射温度（MRT）が減少し、歩行者の感じる温熱環境が大幅に改善されることを明らかにする等、非常に興味深い知見を得ている。さらに、数値解析結果から算出されたSET*の空間分布と前述の被験者アンケートの結果から導かれたSET＊とacceptable rateの関係から、各ピロティ率とacceptable rateの関係を明らかにしている。これは亜熱帯蒸暑気候下の建築計画の設計資料としても有益なものである。

以上のように、本研究は屋外環境実測、被験者アンケート、気候数値解析の結果を総合的に利用し、ピロティがもたらす市街地居住環境の改善効果を詳細かつ定量的に評価したはじめての試みである。ここで得られた知見は、蒸暑気候下の諸地域の建築計画や市街地計画に様々な示唆を与えるものである。また、本研究で提案された被験者アンケートの結果と関連付けて気候数値解析により予測された屋外環境の温熱快適性を評価するという研究手法は、壁面緑化、保水性建材、樹木配置をはじめとする他の環境配慮手法の評価にも展開可能なものであり、この点も高く評価される。

よって、本論文は博士(工学)の学位論文として合格と認める。