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Influence of patio on indoor environment in a Chinese traditional folk house in summer

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Abstract: A case study is performed on the influence of the patio on the indoor environment of a traditional folk house group, named Zhangguying village in Hunan province, in the summer of 2007. Measurements include indoor and outdoor air temperature, indoor and outdoor illuminance, indoor and outdoor air speed, and carried out from August 5th to 10th. The results show that the patio, acting as a "buffer zone", can reduce the ambient impacts on the indoor thermal environment of rooms because the temperature of the patio is lower than that of the outdoor temperature but higher than that of the rooms. The patio can improve the indoor lighting environment because the illuminance of the patio is lower than that of outdoor and higher than that of the rooms. But the effect is too limited, because the illuminance of the rooms is lower than the national standards. This study shows that the shading design is the primary consideration in this kind of climate. The wind speed of the patio is stable and similar to that of the hall and the stack effect of the patio is not obvious. It shows that the patio is useful for natural ventilation, caused by wind pressure, in summer.

Key words: patio; traditional folk house; indoor environment

Buildings originated from the need for human beings to protect themselves from the adverse impacts of climate. The relationship between architecture and climate has been a major topic of discussion in many recent architectural studies. In particular, traditional folk houses have been shown to provide examples of many useful design practices to control the effects of climate. For instance, in Asia, Ooka[1] and Lee et al. [2] studied traditional folk houses in Japan and Korea, respectively, and identified a number of principles which can be applied to sustainability in building design. In the south of China, most of the traditional folk houses consist of groups of buildings incorporating patio[3]. Chen et al. [4-8] studied the Chinese traditional folk house from the qualitative standpoint, and Wang et al. [9-14] studied the problem by using tests and quantitative analysis. But among these studies, the effects of the patio on the indoor environment were ignored.

This paper presents a case study of a traditional folk house group at Zhangguying village in Hunan province with the objective of revealing the influence of the patio on the indoor environment in hot-summer and cold-winter zones. The study was carried out in the summer of 2007 and the results show the positive effects of the patio on the indoor environment. The results and analysis are useful for architects in modern residential building design for achieving a comfortable indoor thermal environment without artificial equipment, which are worthy of being popularized in the countryside of China due to low costs.

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1 Method

1.1 Local climate

Zhangguying village is located in the northern part of Hunan province at east longitude 113.48° and north latitude 29°. This part of China has a subtropical climate: humid throughout the year, hot in summer and cold in winter. The annual average temperature is about 17 ℃. The maximum annual temperature is 41 ℃ and the minimum temperature is −3 ℃. The annual average relative humidity is 79%. The hottest month is July or August and the coldest month is January.

1.2 Test house

Zhangguying village is divided into three parts. The first was constructed in 1562 and is referred to as the Dangdamen building complex; the second and third were constructed at the beginning of the 18th century. In the village, there are altogether 62 lanes, 206 atriums and 1 732 rooms. The overall building floor area is more than 5×10^4 m^2. The house investigated in this study forms part of the Dangdamen building complex, and the section and plan of the main building is illustrated in Fig. 1, which is the object of this study.

1.3 Measurements

Field measurements were conducted from August 5th to 10th, 2007. The following factors were measured: 1) outdoor air temperature, 2) indoor air temperature distribution, 3) indoor and outdoor air speed, and 4) indoor and outdoor illuminance. A portable weather station mounted at a height of 10 m was used to measure outdoor air temperature and wind speed. Data were recorded at intervals of 20 min. The indoor air temperature was measured at a height of 2 m from floor level and the data were recorded every 5 min. Furthermore, the dataloggers were covered by silver paper in order to reduce the influence of lighting at night. Outdoor and indoor illuminance was measured with the illumination meters at a height of 0.75 m (the height of working plan). The indoor air speed was measured at a height of 1.5 m at 9:00 and 15:00 each day, taking the average value over 2 min of measurements recorded at 20 s intervals. The locations of the measuring points are shown in Fig. 1. Details of the instrumentation used are shown in Tab. 1. In particular, before the study, calibration of all instruments was performed by the Hunan University Calibration Service.

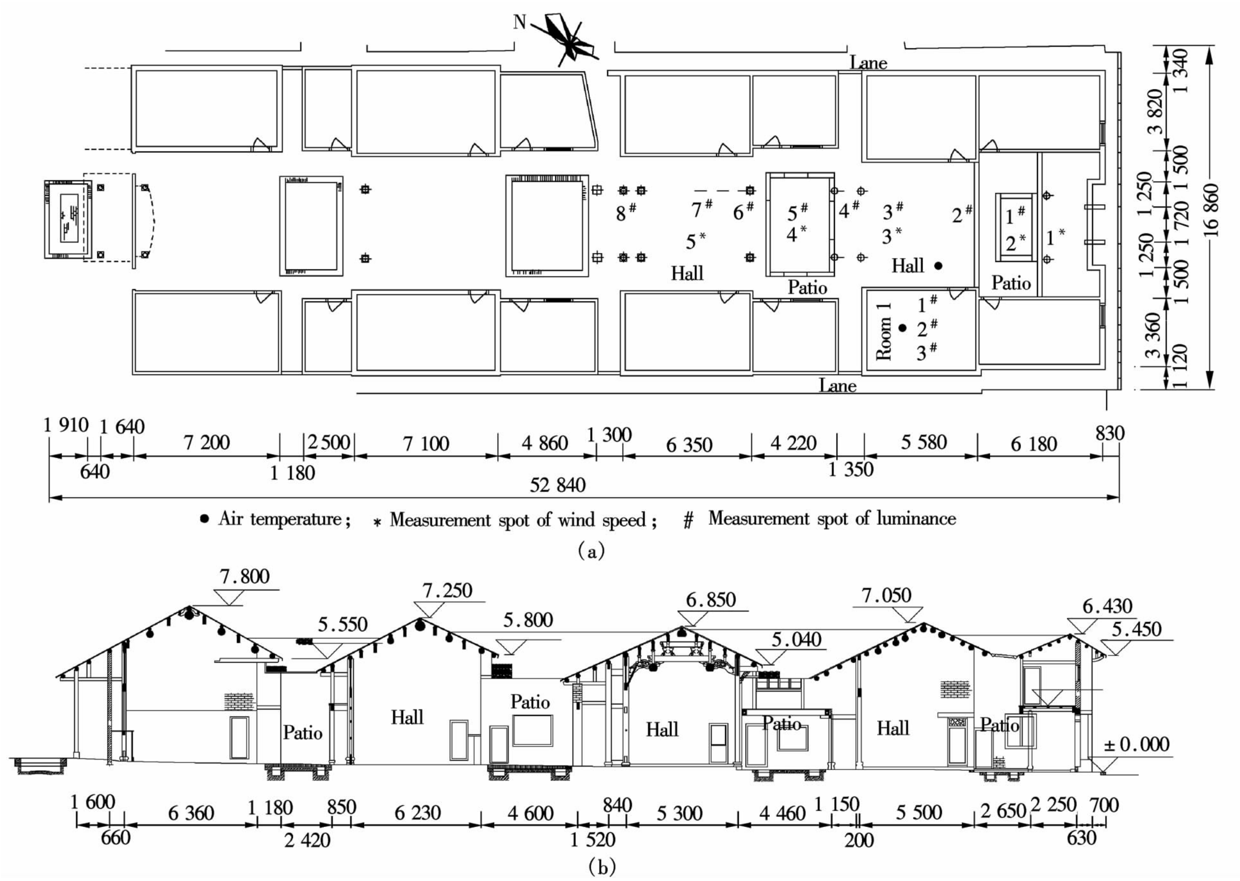

Fig. 1 Section and plan of the main building in Dangdamen building group. (a) Plan of the main building (unit: mm); (b) Section of the main building (unit: m)

Tab. 1 Measured parameters and instruments

Measured parameters	Instruments	Unit type	Precision
Outdoor air temperature and outdoor wind speed	Portable weather station	Casella NOMAD	±0.3 ℃
Indoor air temperature	Temperature datalogger	Testo 175-H2	±0.5 ℃
Indoor air speed	Hot wire anemometer	QDF-30	±0.5%
Outdoor and indoor illuminance	Illumination meter	MAVOLuX5032C	±0.1 lux

2 Results and Discussion

2.1 Comparison of indoor temperature

In the hot-summer and cold-winter climate zone, transitional space and shading are important considerations in traditional house design to avoid solar radiation. Chun et al.[15] studied the effects of transitional spaces in modern buildings. Few investigations with concrete conclusions on the effect of transitional spaces in traditional folk buildings have been shown in literature. The patio is an important kind of transitional space in the Dangdamen building complex, as shown in Fig. 1. The plan area of the patio in this village ranges from 2 to 6 m^2 with a longer dimension on the east-west axis and the ratio of the patio depth to height is about 1 : 2. Furthermore, the patio connects to the hall without any barriers on the south-north axis.

The indoor air temperatures measured in the traditional building during the period from August 5th to 10th, 2007 are shown in Fig. 2. In comparison with the outdoor air temperature, the air temperatures of room 1, the patio and the hall were lower in the daytime and became a little higher at night. This pattern is related to the effect of heat storage by the building's structure and shading by the roof. The air temperatures of the patio and the attic are almost the same. This should be due to the open plane design between the patio and the hall. Compared with outdoor temperature, the temperature of the rooms is very stable. It shows that the patio and the hall act as "buffer zone" and can reduce

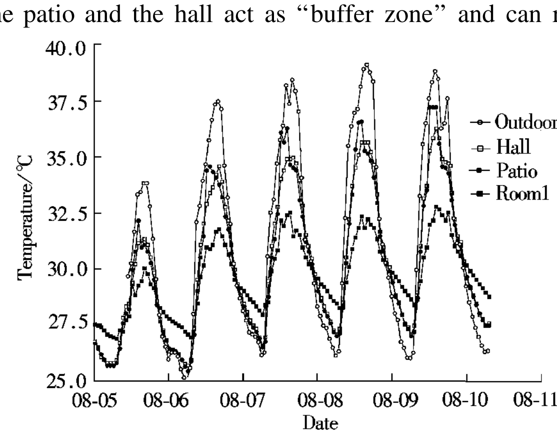

Fig. 2 Variations of indoor air temperatures from August 5th to 10th, 2007

the impact of the outdoor climate on the main living space by providing shade during the daytime. The temperatures of the “buffer zone” are higher than those of the rooms in the daytime. This is believed to be a result of the air temperature in the “buffer zone” being more directly influenced by the outdoor air temperature, due to the high level of outdoor ventilation resulting from the warming of the roof during the daytime.

2.2 Relationship between the patio and natural ventilation

The distribution of measuring points for indoor air speed is shown in Fig. 1. Only the hall and the patio are chosen for measurements of air speed because occupants are accustomed to stay in the hall and the patio until midnight. The results are shown in Tab. 2, which lists the average speed over 2 min periods. The air speed in the hall and the patio are found to be very stable at about 0.2 to 0.5 m/s even when the outdoor wind speed is very low (at only 0.02 m/s). It is because the hall and the patio are open to the south and the north, the main direction of natural wind, without any barriers. Furthermore, it also shows that the natural ventilation of the building complex is aided by the flat topography to the south of the building complex.

A common statement is that the patio of the traditional folk house is good for natural ventilation because of the stack effect. The measuring points $2^{\#}$ and $4^{\#}$ are situated in the patio. The results show that the air speeds at points $2^{\#}$ and $4^{\#}$ are similar to those at other points in the same line. The results suggest that air velocity at $2^{\#}$ and $4^{\#}$ are influenced by the wind pressure but not by thermal pressure. Furthermore, there is no heat source in the atrium. It is suggested that solar radiation may be regarded as a heat source. But in an atrium in the Dangdamen building complex, direct solar radiation can only enter for a short period because of the good shading design. It follows that the natural ventilation of traditional folk houses in this area is mainly influenced by the predominantly southern wind in summer. It is one reason why the village lies in a small basin at the foot of a hill facing south. The cold wind in winter from the north is blocked by the mountain and the summer wind from the south can enter the building complex without any hindrance.

Tab. 2 Outdoor wind speed and average air speed measured in the hall and the patio m/s

Parameters		August 6th		August 7th		August 8th	
		9:00 to 9:10	15:00 to 15:10	9:00 to 9:10	15:00 to 15:10	9:00 to 9:10	15:00 to 15:10
Outdoor wind speed		1.98	0.06	2.89	0.23	0.02	0.22
Average air speed in the hall and the patio	1^{*}	0.35	0.32	0.44	0.49	0.56	0.23
	2^{*}	0.22	0.17	0.21	0.17	0.27	0.19
	3^{*}	0.29	0.16	0.16	0.12	0.10	0.14
	4^{*}	0.44	0.33	0.17	0.18	0.14	0.20
	5^{*}	0.46	0.20	0.12	0.16	0.13	0.15

2.3 Relationship between the patio and the lighting environment

Fig. 1 shows the location of the points at which the illuminance was measured. Tab. 3 gives the values of outdoor illuminance and indoor illuminance in the hall, the patio and the rooms. The illuminance of the patio was measured at points $1^{\#}$ and $5^{\#}$ in the hall. Within the building complex, the best lighting environment is in the patio as a result of its large opening. The lighting environment of the hall is not so good as that of the patio but better than that of room 1. It is because that there are no walls between the hall and the atrium and daylight can readily enter the hall. The lighting environment of room 1 in daytime is, however, less satisfactory. The luminance of the measuring points in room 1 is less than 100 lux, which is lower than the national standard for residential buildings. The window and the door of room 1 are open to the patio to provide natural lighting, but the effect is limited by the size of the patio. However, it is the only way for ancient people to adjust the lighting environment in the daytime for a building complex with large depth.

Tab. 3 The illuminance measured in hall, patio, room and outdoor lux

Location		August 6th		August 7th		August 8th		August 9th		Average	
		9:40	15:20	9:40	15:20	9:40	15:20	9:40	15:20	9:40	15:20
Outdoor		80 000	87 000	66 000	60 000	69 000	91 500	76 000	42 000	72 750	70 125
Hall and patio	$1^{\#}$	2 150	2 000	1 250	1 130	1 390	1 680	580	1 250	1 343	1 515
	$2^{\#}$		1 270	1 450	600	1 450	1 050	620	940	1 173	965
	$3^{\#}$	890	760	620	440	600	480	400	600	628	570
	$4^{\#}$	2 000	5 600	1 430	3 150	1 580	3 450	630	2 600	1 410	3 700
	$5^{\#}$	8 220	6 800	3 640	3 710	4 100	5 650	1 600	4 900	4 390	5 265
	$6^{\#}$	2 550	3 440	4 160	1 600	4 600	2 150	1 850	2 900	3 290	2 523
	$7^{\#}$		910	1 450	400	1 540	500	480	770	1 157	645
	$8^{\#}$	520	170	330	140	320	160	150	160	330	158
Room 1	$1^{\#}$	75	100	43	63	79	106	59	65	64	84
	$2^{\#}$	22	42	10	8	4	63	7	25	11	35
	$3^{\#}$	6	7	7	9	7	14	12	7	8	9

Of course, the size of the patio can be expanded for more sunshine to improve the indoor lighting environment of room 1. But, the indoor thermal environment will be damaged in this way. Then, a conflict between the lighting and thermal environments occurs. In the past, there were few technologies to control the indoor thermal environment without air-conditioning. So, shading is the primary consideration to improve the indoor thermal environment and the lighting environment has to be ignored. It suggests that designers should consider all aspects of a building and choose a priority when issues conflict.

3 Conclusion

A program of field measurement and analysis has been undertaken to clarify the relationship between the patio and the summer indoor environment of a traditional Chinese folk house in Hunan province. The findings provide a new insight into a previously held view, stack effect in the atrium, concerning traditional folk houses. The important but previously ignored characteristic, the effect of transitional spaces, has been identified.

In summary, there are three main findings from this study which can be applied to modern building design for sustainability. First, the patio is a useful passive technique to improve the indoor lighting environment for residential buildings with large depth, even though the effect is limited by the size of the patio. Secondly, the patio is a useful passive technique to improve the indoor natural ventilation in the buildings. The openings on the north and south sides of the patio should be designed as large as possible in order to reduce obstruction effects. Finally, the action of transitional spaces, including the patio and the hall, as a climate "buffer zone" has been confirmed. The shading effect of these spaces on rooms is clear and can also be incorporated in modern building design. However, although it provides improvements to the indoor thermal environment in summer, the extended use of shading to limit solar gain reduces the potential for natural lighting. So, the patio in the residential buildings with large depth requires careful consideration to ensure an indoor environment that provides both thermal comfort and satisfactory lighting conditions.

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中国某传统民居天井对夏季室内环境的影响

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摘要:针对传统民居中天井对夏季室内环境的影响,在 2007 年夏季对湖南张谷英村的传统民居建筑群进行了连续监测.监测项目包括室内外气温、室内外照度以及室内外风速,检测时间从 8 月 5 日至 10 日.结果显示:天井气温低于室外气温高于室内气温,表明天井作为"气候缓冲空间"能降低外界对室内热环境的影响;天井照度低于室外高于室内,表明天井能改善室内光环境.但是室内照度低于国家标准,说明改善效果极其有限,也表明遮阳设计依然是当地气候条件下的首要考虑因素;天井风速稳定且与堂屋风速接近,说明天井能促进夏季由水平风压引起的自然通风,但其烟囱效应并不明显.

关键词:天井;传统民居;室内环境

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