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PRELIMINARY STUDY OF INDOOR FEATURES OF TEMPERATURE AND HUMIDITY FOR ROOMS FACING NORTH-SOUTH IN WINTER IN A LOW-LATITUDE PLATEAU CITY

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ABSTRACT: Analyzing observations of wintertime air temperature in both indoor and outdoor surroundings in Kunming, a city lying in low latitudes, characteristics of temperature and humidity have been studied for the interior of rooms facing north-south under different weather conditions. Significant warming effect has been identified in terms of lowest and daily-mean indoor temperature in the area of Kunming. The heating amplitude ranges from 7.7°C to 10.0°C and from 4.6°C to 5.8°C for the interior part of rooms facing the south and from 4.6°C to 7.0°C and from 1.3°C to 4.4°C for the interior part of rooms facing the north, respectively for the two elements. The highest air temperature is higher indoor than outdoor for rooms facing the south, but otherwise is usually true for rooms facing the north. Additional findings point out that buildings not only help maintain relatively warm indoor temperature but delay its variation. The diurnal cycle of temperature indoor is smaller and ranges by 40% ~ 48% for south-facing rooms, and by 20% ~ 30% for north-facing rooms, than outdoor, and the highest temperature is about 2 hours late inside the room than outside. It shows how inertly indoor temperature varies. The work also finds that relative humidity is less indoor in southward rooms than in northward ones and difference is the largest on fine days but the smallest when it is overcast. For the diurnal variation, the indoor relative humidity is large at nighttime with small amplitude but small during daytime with large amplitude. The above-presented results can be served as scientific foundation for more research on climate in low-latitude cities and rational design of urban architectures.

Key words: orientation of room; air temperature and humidity; different weather condition; winter; low-latitude plateau city

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1 INTRODUCTION

With the development of cities, urban climate effect has been increasing and drawing growing concerns. At present, research focus on urban climate in developed countries over the middle and higher latitudes from subtropical to extratropical zones rather than low-latitude or developing nations^[1]. In China, urban climate is a subject mostly for large and medium-sized cities like Shanghai, Beijing and some others on the coast^[1-6] but studied far less as much for low-latitude plateau regions in western China. For Kunming, attempts have been made to discuss the climatic difference in and out of the urban districts, but only with short-term observations^[7-9].

Housing is a shelter for human being to seek safety and get rid of all kinds of inadequate dwelling conditions. It has now evolved into a living place functioning comprehensively, which dwellers cannot live without. To meet demands from its occupants, research on interior surroundings inside a building has gained more and more attention. The condition of indoor

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temperature and humidity is one of the key indexes for assessing interior comfort of a room and therefore widely taken seriously. For the field of architecture, there is already much work on the effect of environmental conditions on living^[10-12] but few has ever dealt with indoor temperature and humidity in rooms with different orientations in areas lying on low-latitude plateau.

How a room keeps warm and resists cold is an important criterion in architectural design. Study in this regard may provide the designer with what is required for reasonable results. Using meteorological observations on the yard and the third floor of a building with windows facing both north and south in the urban proper of Kunming during wintertime, the current work discusses indoor features of temperature and humidity under various wintertime weather conditions in the low-latitude city on plateau and the difference between the yard and the third floor. It is hoped that the research may be of scientific foundation for more study of climate in low-latitude plateau cities and reasonable design of architecture concerned.

2 SUMMARY OF THE STUDY

Sitting in an area of low latitude (25°N, 103°E) and high altitude above sea level (1892 m), the city of Kunming is exposed to joint effects of general circulation, geographical location and altitude above sea level (ASL) such that a climatic setting is formed that is spring-like all the year round. Substantial fall in temperature does happen when powerful masses of cold air progress southward in the winter. As heating facility is largely absent in the city, its natural conditions have become a desirable platform on which effects of environmental change on air temperature indoors are performed.

The observation was taken on the courtyard, roof and the third floor of the office building for the Kunming branch of Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences. Elements measured included dry-and-wet-bulb temperature, highest and lowest air temperature, wind speed and direction inside the courtyard and on top of the roof, plus total and low cloud cover. The observation began from November 1998 following meteorological specifications at a density of three times a day (0800, 1400 and 2000). A self-recording thermograph (TR-71, made by T&D, Japan) was used to record dry-and-wet-bulb temperature at intervals of 5 minutes over the period from December 25, 1999 to January 18, 2000.

The point of observation was largely at the center of the courtyard with the instrument recording temperature and humidity installed inside a screen that stood on grass as the underlying surface. The roof observation point was on the top of a four-storied office building with precast bricks made of concrete as the underlying surface. The indoor observation was roughly at the center of two rooms either facing north or south in the eastern flank of the building — they are comparable in size (about 35 m²) with the eastern and southern (northern) walls on the external side, which are built with orange mosaics in thickness of 0.33 m. The inner height of the rooms was 3.2 m. The windows were of single plates of glass fixing on both northern and southern surfaces of wall, taking up about 40% of the total area. The rooms face each other with a corridor going through between them.

For the analysis of weather conditions, the criteria of division is the low cloud cover — fine days are determined when it is less than 30%, overcast weather are set when it is more than 80% and the sky is said to be cloudy when it is between 30% and 80%.

It is with the data of dry-and-wet-bulb temperature, highest and lowest temperature measured indoors and at the courtyard from December 1998 to February 1999 that the mean values of air temperature and humidity during fine, cloudy and overcast days are studied. For the diurnal variation of the two elements, the observations taken at 5-minute intervals from December 25, 1999 to January 18, 2000 are used and on-the-hour values are the mean of 5 observations

measured 20 minutes across the hour (10 minutes before and 10 minutes after).

3 RESULTS AND ANALYSES

3.1 Mean air temperature

3.1.1 CHARACTERISTICS UNDER DIFFERENT WEATHER CONDITIONS

For the mean highest temperature at each point of observation (Fig.1a), fine days had the highest measurement but overcast had the lowest; it was 4.5°C higher in fine days than in overcast days in the courtyard, and the difference is 3.9°C (7.0°C) in the interior of southward (northward)-facing room.

For the mean lowest temperature distribution under different weather conditions (Fig.1b), the lowest value was recorded in the courtyard, which was most subject to cold air activity; the maximum value occurred in cloudy days rather than in fine days. It shows that during nighttime the heat loss is the largest if the sky is cloudless but the outgoing longwave radiation was blocked up by clouds if it is cloudy. The result was that the lowest temperature was higher when it was cloudy than when it was fine. The difference of indoor lowest temperature was not as much between the rooms with different orientation when it is fine and cloudy; the southward (northward)-facing room was 1.5°C (5.4°C) lower when it was overcast than when it was fine, for the lowest temperature indoors. As far as the combined mean lowest temperature is concerned, the indoor temperature is similar to that in fine days in both rooms.

For the mean temperature distribution under different weather conditions (Fig.1b), we know that it is the highest in fine days and lowest when it is overcast at all locations of observation, being similar to the case of highest temperature. The study shows that the mean lowest (highest) temperature is 5.6°C (8.9°C) with the sky overcast resulting from the effect of cold air in the winter of Kunming — a city of ever green the year around.

3.1.2 DIFFERENCE OF TEMPERATURE IN AND OUT OF THE ROOMS UNDER ALL WEATHER CONDITIONS

Tab.1 shows the temperature difference at the courtyard between the indoor and outdoor surroundings in the two rooms under all weather conditions. It is seen that it is the largest in the lowest air temperature — a rise of 7.7°C ~ 10.0°C (4.6°C ~ 7.0°C) could occur in the room facing the south (north). It is obvious that the warming effect is quite significant in low-latitude plateau.

For the difference in the highest temperature between indoors and the courtyard outside, the rooms had different values according to the orientation. It is always positive in the south-facing room, ranging from 2.0°C to 4.0°C, which is similar to the result of the Haifa Institute, USA (3.5°C)^[11]. The finding shows that the south-facing room helps increase the highest as well as the

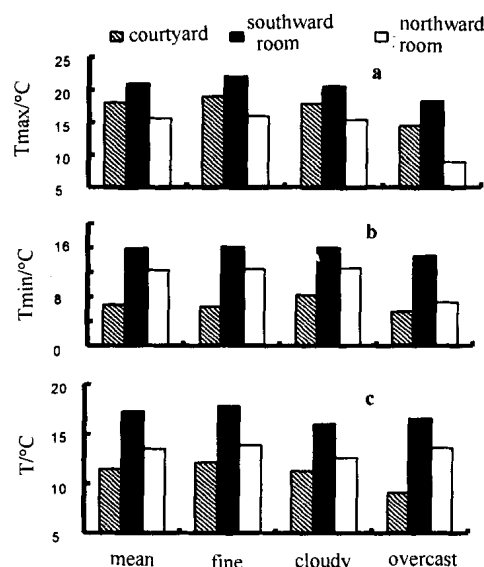


Fig.1 Mean air temperature (°C) under all weather conditions.

lowest temperature. In the interior of the northward-facing room, however, the lowest temperature is higher than in the outdoors while the highest temperature is lower or near that in the outside. For the daily mean temperature, it is always warmer indoors southward than outdoors northward, regardless which orientation the room faces.

Tab.1 Difference of air temperature between indoors and the courtyard outside (°C)

	Highest temp.		Lowest temp.		Diurnal mean temp.	
	S	N	S	N	S	N
Fine	3.1	-2.6	9.1	5.4	5.8	1.7
Cloudy	2.0	-3.0	7.7	4.6	4.6	1.3
Overcast	4.0	0.1	10.0	7.0	7.4	4.4
mean	3.0	-2.2	8.9	5.5	5.8	2.1

Studying from the point of weather conditions, the largest difference of temperature between indoors and outdoors is recorded when it is overcast and smallest when it is cloudy. The indoor / outdoor difference can be 7.4°C (southward) and 4.4°C (northward) in terms of daily mean temperature with overcast sky. It indicates that it is possible for the daily mean temperature indoors to increase by 4.4°C ~ 7.4 °C in winter over low-latitude plateau areas, even if there is no heating supply.

3.1.3 CHARACTERISTICS OF DIFFERENCE OF INDOOR TEMPERATURE BETWEEN NORTHWARD AND NORTHWARD ROOMS

Next is more discussion on the effects of northward / southward orientation on air temperature indoors (Tab.2). Regardless of the sky condition (fine, overcast or overcast), indoor (highest, lowest and mean) temperature is always higher inside the southward-facing room than the northward-facing one, with the difference ranking in the order of highest > mean > lowest temperature; difference between the two rooms was the largest when it was fine but smallest when it was overcast. From a combined mean, we know that the difference of indoor temperature in the rooms was 5.2°C for the highest, 3.4°C for the lowest and 3.7°C for the diurnal mean.

Tab.2 Difference of mean indoor temperature between the northward-facing and southward-facing room (°C)

	Highest temp.	Lowest temp.	Diurnal mean temp.
Fine	5.6	3.7	4.1
Cloudy	5.0	3.1	3.3
Overcast	3.9	3.0	3.0
mean	5.2	3.4	3.7

3.2 Characteristics of diurnal range in air temperature under all weather conditions

More study of diurnal range of temperature at all points of observation (Fig.2) has shown that it is relatively small indoors, which is less than 50% of that at the courtyard, with the rate of appearance for the southward room (40% ~ 48%) larger than the northward room (20% ~ 30%). The largest diurnal range of temperature was recorded at the courtyard and the smallest inside the northward room. Under all weather conditions, the difference is the largest in fine days, followed

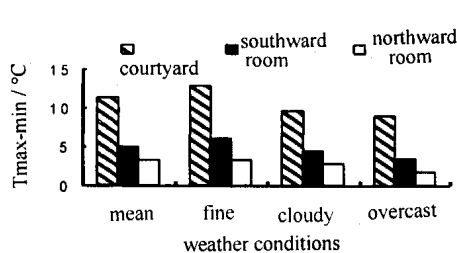


Fig.2 Diurnal range of air temperature (°C) under all weather conditions.

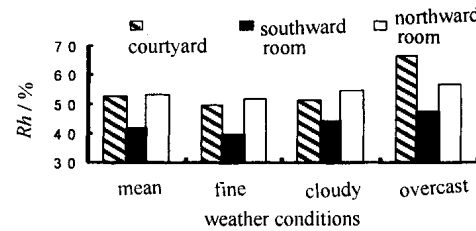


Fig.3 Mean relative humidity (%) under all weather conditions.

in turn by cloudy and overcast sky. It is as much as 8.9°C at the courtyard even when it is overcast, fully reflecting the climate feature of the Kunming area. The indoor diurnal range is relatively small, being 3.6°C (southward) and 1.8°C (northward) respectively, showing that rooms can stabilize air temperature indoors when it is overcast.

3.3 Characteristics of mean relative humidity

For the general tendency, mean relative humidity (Fig.3) is the largest in overcast days but smallest in fine days, for both indoor and outdoor surroundings. When it is fine or cloudy, it is larger at the courtyard than the southward room indoors; when it is overcast, it is the largest again at the courtyard, followed by the northward room indoors and then by the southward room indoors. The last location can be about 20% less than surroundings outside the room. For the combined mean relative humidity, the northward room is similar indoor to the outside, with the southward room being smallest (41.8%).

Viewing from the difference of mean relative humidity between indoors and outdoors (Tab.3), we know that it is always negative inside the southward room, the northward room is positive when it is fine and cloudy, showing for the northward room that relative humidity is higher indoor than outdoor only when it is fine or cloudy and it is the lowest when it is overcast indoor the southward room. In addition, the difference in relative humidity between the two rooms indoor is the largest in fine days (-12.1%) and smallest in overcast days (-9.8%), with comprehensive mean at -11.3%. Next is the study of diurnal variation of temperature and humidity in and out of the rooms.

Tab.3 Difference of relative humidity under all weather conditions (%)

		fine	cloudy	overcast	mean
Indoors vs. outdoors	S	-9.8	-7.2	-19.7	-10.8
	N	2.3	3.3	-9.9	0.5
S vs. N		-12.1	-10.5	-9.8	-11.3

3.4 Diurnal variation of temperature and humidity

3.4.1 DIURNAL VARIATION OF AIR TEMPERATURE

Similar patterns exist for the diurnal variation of indoor air temperature in the southward and northward rooms over the wintertime (Fig.4a). The maximum value occurred around 1700 L.T. (same below) while the minimum appeared at different time of the day, from around 0800 for the

southward room to around 0700 for the northward one. The difference between the rooms was the largest at 1700 and the smallest at 0900. Apart from it, the curve for diurnal variation of the temperature difference as shown in Fig.4b indicates that the fall of temperature was quite large after the maximum value and indoor temperature rose slower in the mornings than it dropped in the afternoons.

With regard to the diurnal variation, temperature at the courtyard outside (Fig.5a) showed in a way different from the indoor setting — the minimum appeared at the same as the southward room around 0800 but the maximum was at 1500, about 2 hours earlier than indoor. It shows that buildings can delay the time of appearance for extreme air temperature indoor. Fig.5b gives the diurnal variation of temperature difference between the interior of the two rooms and the courtyard outside: $\Delta T > 0^{\circ}\text{C}$ for all day in the southward room with the difference larger at night than during the day, and maximum difference appeared at 0800 and minimum difference at 1400; the difference of air temperature between the northward room and the courtyard is positive at night but negative during the day, with the diurnal variation larger than the southward room.

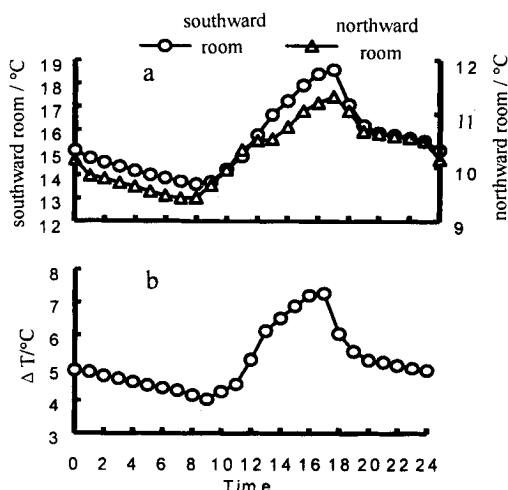


Fig.4 Diurnal variation of mean indoor air temperature ($^{\circ}\text{C}$) and difference between the southward and northward rooms (b).

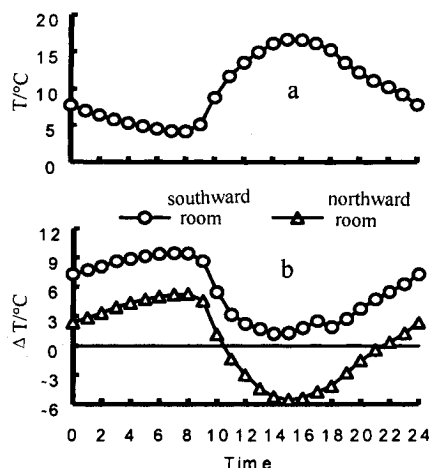


Fig.5 Same as Fig.4 but for the courtyard (a) and between indoors and the courtyard (b).

3.4.2 DIURNAL VARIATION OF RELATIVE HUMIDITY

From the diurnal variation of indoor relative humidity (Fig.6a), we know that the humidity is high and varies little at night but it is low and varies much during the day, with the maximum at 0900 for the southward room, about 2 hours late compared to the northward (0700); the minimum all occurred at 1700 for both rooms. The south-north difference in relative humidity indoor (Fig.6b) is always negative, indicating drier indoor surrounding in the southward room than the northward one.

The diurnal variation, large at night but small during the day, is also present in the relative humidity at the courtyard outside (Fig.7a), though with the maximum at 0800, which is earlier than the southward room indoor but later than the northward room indoor; the minimum appeared at 1500, about 2 hours earlier than indoors; the diurnal variation is also larger than indoors. Studying the difference of relative humidity inside and outside the room (Fig.7b), we find that the difference between the southward room and the courtyard is negative at night and large in

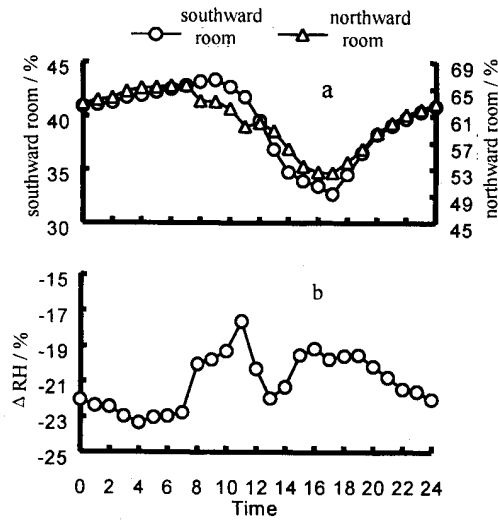


Fig.6 Diurnal variation of mean indoor relative humidity (a) and difference between the southward and northward rooms (b).

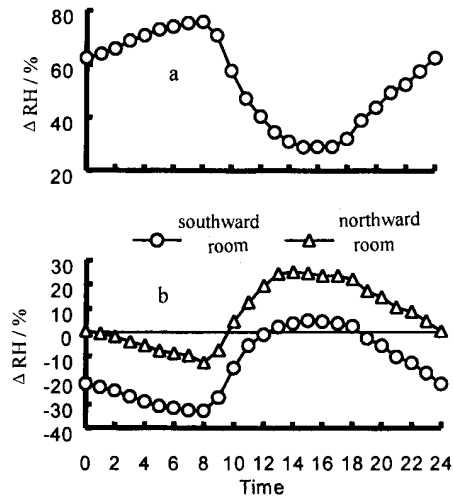


Fig.7 Same as Fig.6 but for the courtyard (a) and between indoors and the courtyard (b).

absolute value, with the difference being the largest at 0800 (-32.7%) and relatively small between 1100 and 2000 when relative humidity is generally comparable to outdoors. In contrast, the difference of relative humidity is small / negative at night but large / positive during the day between the northward room and the courtyard; the maximum positive difference appeared at 1400 and the maximum negative difference at 0800.

4 CONCLUDING REMARKS

Indoor air temperature and humidity are one of the main indexes for accessing the comfort of buildings. By studying the difference of temperature and humidity indoor the southward and northward oriented rooms in Kunming, a plateau city in low latitude, we have obtained the following results.

a. Due to the heat preserving effect of buildings, diurnal mean temperature and mean lowest temperature is always higher (especially so when it is overcast) indoor than outdoor in the winter of Kunming, under all weather conditions and even without heating facilities. In contrast, the highest temperature of the day is higher (lower) indoor than outdoor for the southward (northward) room.

b. Buildings can substantially reduce the diurnal range of temperature. The indoor difference is less than 50% of that at the courtyard, with the ratio of appearance for the southward room ($40\% \sim 48\%$) higher than the northward room ($20\% \sim 30\%$), for all conditions of weather.

c. Buildings in the area of Kunming also delay the time of occurrence for the highest indoor temperature during the daytime. It appears about 2 hours later than that outdoors.

d. The diurnal variation of the difference between the indoor and the courtyard temperature differs greatly with what direction a building faces. In the southward room indoor, $\Delta T > 0^\circ\text{C}$ for all the time of the day, which is larger at night than during the day, with the maximum at 0800 and the minimum at 1400; in the northward room indoor, however, the difference is positive at night but negative during the day with the diurnal variation larger than the southward room.

e. For the indoor relative humidity, it is the largest in the northward room indoor and higher than the courtyard; it is the smallest in the southward room indoor and lower than the courtyard,

when it is fine or cloudy; it is the largest at the courtyard and smallest in the southward room indoor, with the courtyard in between. For the comprehensive relative humidity in the northward-facing room, it is close to the courtyard outside (52.6%).

f. For the indoor relative humidity, it is lower in the southward room than the northward one and the difference is the largest in fine days and the smallest in overcast days.

g. For the diurnal variation of indoor relative humidity, it is higher and varies little at night but lower and varies much in the daytime; the maximum occurs at 0900 in the southward room, later than that at the courtyard while it is at 0700 in the northward room, earlier than the courtyard.

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