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(出版者 / Publisher)
法政大学工学部
(雑誌名 / Journal or Publication Title)
法政大学工学部研究集報 / 法政大学工学部研究集報
(巻 / Volume)
42
(開始ページ / Start Page)
33
(終了ページ / End Page)
40
(発行年 / Year)
2006-03
(URL)
https://doi.org/10.15002/00003749

Field Measurements on Thermal and Air Environments of Underground house in Matmata, Tunisia

Kiyotaka DEGUCHI,*
Mayumi OHI*, Kenta SAKAI* and Yuko SUZUKI*

This paper deals with the field measurements on thermal and air environments of underground house in Matmata, Tunisia. The effects of thermal capacity of the soil were analyzed by measurements. Thermal conductivity of soil was also examined. It was clarified that cave rooms are more comfortable than the outside because oil of the house hardly transfer the heat.

Keywords: Field measurements, thermal and air environment, Matmata, underground, vernacular

1. Introduction

There are various kind of underground vernaculars oll over the world such as Yao-Dong in China, in Cappadocia of Turkey, in Coober Pedy of Australian , etc. They are mostly situated in dry climate regions. In Matmata, the south area of Tunisia, underground houses existed for a long time. Matmata's type is similar to Yao-Dong in China.

As Matmata is a desert climate area which is dry through all the year and awfully hot in summer, underground house is well evaluated as a place for comfortable life. But there are not many data to examine thermal and air environment of these underground houses in Matmata. In these reasons, it is necessary to clear effectiveness and comfort of the underground house by inspecting the house in Matmata.

2. Outline of the measuring area

Tunisia is located at the middle of Mediterranean coast in South Africa. (Fig.1) It is the opposite of the Sicilia Island in Italy and bounded on Libya and Algeria. Mediterranean coast expands 1300km from the north end to the east end of the country. The south of Tunisia is a part of the Desert of Sahara and the area of the country is 164,154km^2.[3] The population is 994million.[4]

The house inspected is in Matmata. Matmata is 360km south from the capital Tunis. (Fig.2) It's in the area of mountains about 500m high, near the Desert of Sahara. A climate zone is between Steppe and Desert. In summer, maximum mean temperature reaches 35℃ and precipitation is 230mm in a whole year which is 6 times lower than in Japan.[5]

3. Outline of the house inspected

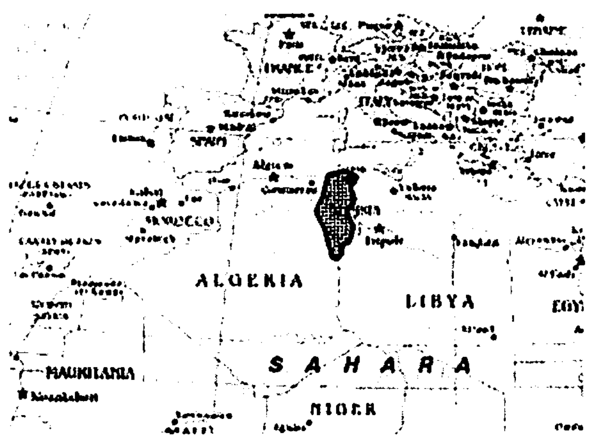

Fig.1 Map of Tunisia 1[1]

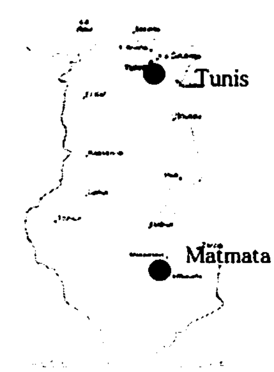

Fig.2 Map of Tunisia 2[2]

*Department of Architecture

The house looks like a hole from the ground because it's built underground (Fig.3 and 4) . The square courtyard is dug under 7m, and each room is dug even with the courtyard like caves. There're a barn and a reservoir on the ground(Fig.5). Residents do a bathing and washing around the reservoir. It's possible to approach to the ground by stairs. The entrance (Fig.6) is the same level as the courtyard. A "skifa" (Fig.7) connects the entrance and the courtyard which is used as a public place for service, dining and taking a nap. As each room has only one door facing to he courtyard (Fig.8), and it has not a wind. From the north of the courtyard to the entrance is a gradual slope which prevents the courtyard from becoming puddles. (Fig.14) The house has a second floor shown in Fig.10 which is used as a as a granary. The occupants climb up with a hung rope to access the second floor. Cooking can be done in three places with ovens and a stove (Fig.11 to Fig.13). The courtyard and each room are plastered which works as repellent.

4. Outline of measuring

In order to examine thermal and air environment, measuring of temperature and humidity was done in the 4 rooms (living room, children's room, bedroom, kitchen), the upstairs granary, the courtyard and skifa (a space connects the entrance and the courtyard). All of these are measured at 1000mm high, from 20:00 Aug. 22nd to 16:00 Aug. 25th. The data of temperature and humidity were gained automatically by the logger. Wind velocity and direction was measured manually at 9:00, 13:00 and 17:00, on several points in the skifa and the courtyard, at height of 2000mm. Then wind velocity and direction at the space from the entrance to the courtyard were gained.

The wind velocity was measured per one point for five minutes, and the maximum and minimum over the five-minutes were also measured. The wind direction was measured by observing the direction of woolen yarn hung-over, watching the wind direction every minute for five minutes.

At the outside of the house, temperature, humidity, solar radiation, wind velocity and direction were measured. Temperature, humidity and solar radiation were measured every five minutes and outside wind direction and wind velocity were measured every ten minutes. The measuring data were recorded automatically by the logger through each measuring instrument. Temperature and humidity were measured at height of 1m, and wind velocity and direction were measured at 2m. Also, heat conductivity of soil around the house was measured in order to know characteristics of soil.

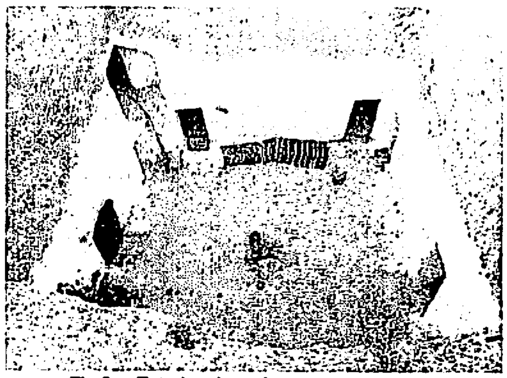

Fig.3 Exterior view of upper part

Fig.4 Upper part view

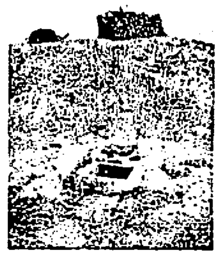

Fig.5 Reservoir

Fig.6 Entrance

Fig.7 Skifa

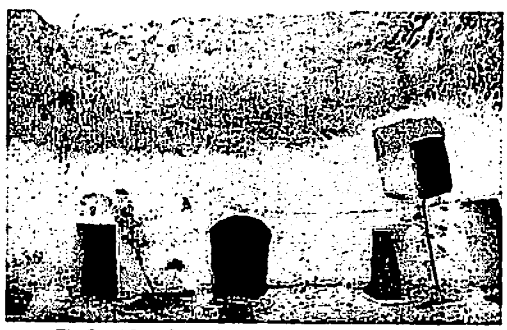

Fig.8 View from the courtyard

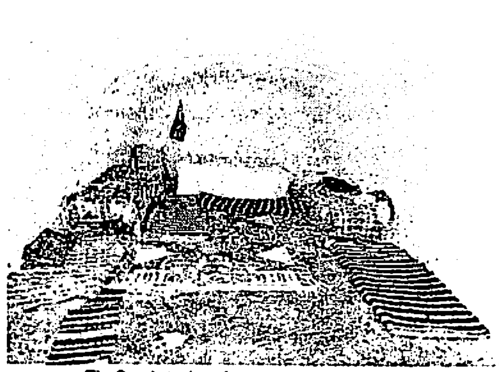

Fig.9 Interior view

Fig.10 Second floor

Fig.11 Furnace for baking bread

Fig. 12 Old kitchen

Fig.13 Current kitchen

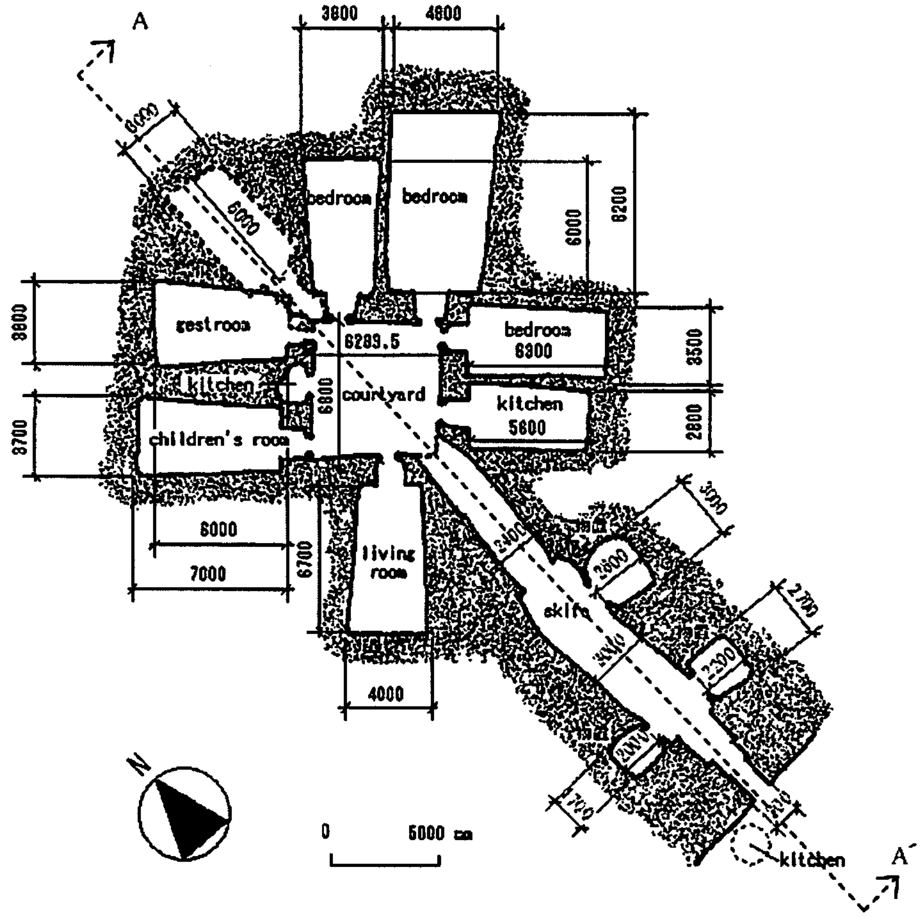

Fig.14 Floor plan

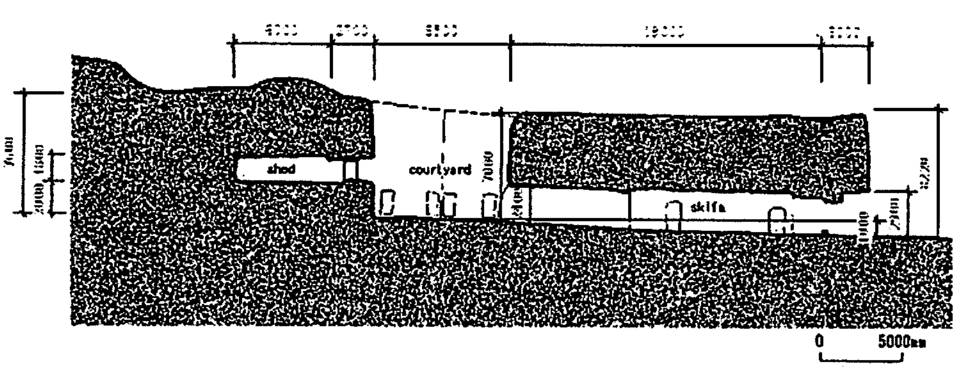

Fig.15 Section A-A'

5. Results of measuring

(1) Thermal environment of outside and inside the underground house

Fig.16 shows temperature and humidity change per hour on the ground. Also, Fig.17 shows solar radiation. Max temperature during the measuring period was 39.5℃ at 14:00 on Aug. 25th, the minimum temperature was 18.3℃ at 6:00 on Aug. 24th. Humidity changed adversely with temperature. Maximum humidity was 81% at 7:00 on Aug. 23rd; the minimum humidity was19% at 15:00 on Aug. 24th. From nighttime on Aug. 22nd to the next morning, temperature was lower and humidity was higher than other days because of the rain on the day before. Except this time, Fig.16 and 17 shows typical climate of the area with high temperature and low humidity.

Change of outside temperature and room temperature was shown in Fig.18 and humidity and room humidity in Fig.19. Because of the strong solar radiation, temperature is getting higher. Maximum and minimum temperatures on Aug. 24th were 37.5℃ and 18.6℃ respectively. On the other hand, room temperature was neither getting higher at daytime nor getting lower at nighttime, because there's no influence from solar radiation and the house is surrounded by soil. Maximum and minimum room temperatures on Aug. 24th were 27.5℃ and 24.0℃ respectively. Temperature difference during the day was 18.9℃ on the ground but only 3.5℃ in the room; therefore, it is obvious that room temperature is stable all day long. Humidity changes in inverse relation to the temperature. Maximum and minimum humidity on Aug. 24th were 70% and 19% respectively. On the contrary, maximum and minimum room humidity in the room was 59% and 40% respectively. Difference between the maximum and the minimum humidity was 51%, but 18% in the room. Room humidity is also stable all day long. Temperature on the ground was getting high in the daytime and getting low in the nighttime; therefore, humidity changes in inverse relation to temperature. In the room, difference between maximum and minimum temperature was small and that of humidity was also small. In addition, temperature was around 27℃ and humidity is 55% all day, and there's no effect from solar radiation. From these circumstances, room thermal environment is more comfortable than outside on the ground.

(2) Ventilation

From the measuring of wind velocity and direction of this time, the ventilation rates were calculated on the skifa which has a definite entrance and exit for the wind. Table 1 shows wind velocity, ventilation rate at each measuring point on Aug. 23rd. Measuring points are shown in Fig. 20. The air volume of the skifa is 101.4m^2. As the results of calculations,

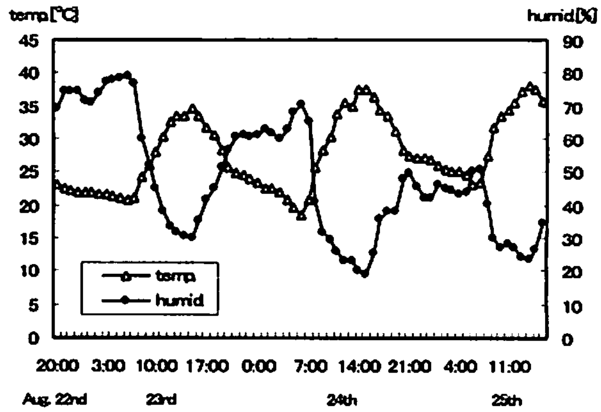

Fig.16 Temperature and humidity on the groud

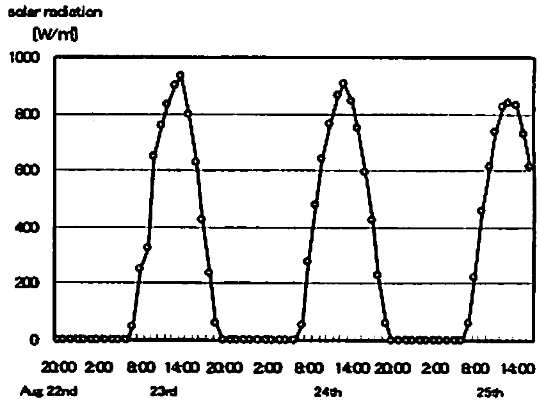

Fig.17 Solar radiation

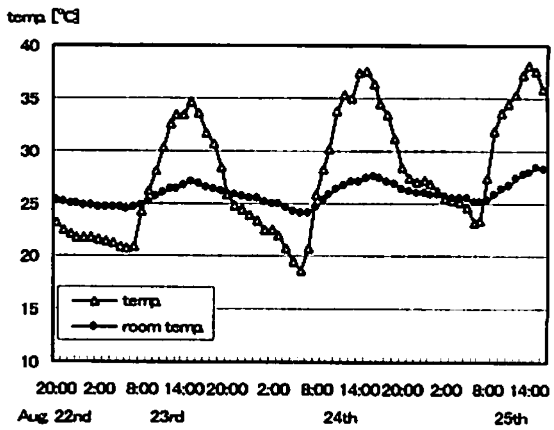

Fig.18 Outside temperature and room temperature

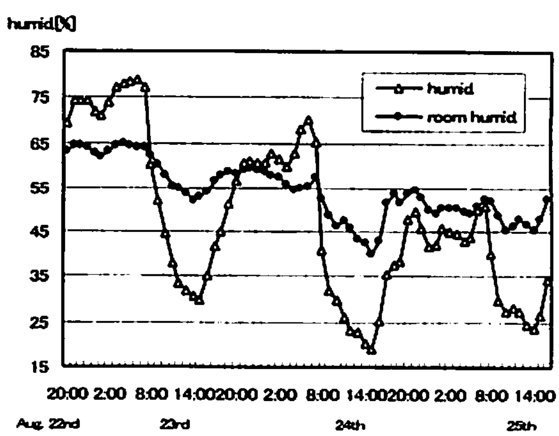

Fig.19 Outside humidity and room humidity

amount of ventilation is over 10000 m^3/h and air change rate is over 100[ach]. It can be said that skifa is well ventilated by wind.

In addition, wind velocity and direction in the rooms were measured. As wind velocity was very low, it was considered that wind didn't blow at all there. Because of that, it was guessed that ventilation in each room was by temperature difference between the courtyard and each room; therefore, ventilation rate were calculated by measured temperature data. The calculations were done in two conditions when the door was open and closed. Models of two conditions are shown in Fig.21. When the door was closed, it was considered that air would flow through upper gaps of the door to lower; therefore, height difference should be the height of the door (h). When the door is open, opening space is thought to be just one, so the opening space was divided into two (top and bottom) in order to regard it as a route of air, then amount and number of ventilation were calculated. The height of each part (h) was regarded as the half of the door height. Residents were sitting, lying, cooking or weaving rugs and number of person at each room was 0 to 4 persons so that situation was assumed that 4 persons doing light work, sitting during the work time.

Table 2 shows results of ventilation rate in each room. When the doors were closed, there wasn't enough ventilation at any time at any room. Even when the doors were open, there wasn't enough ventilation except at 13:00 and 17:00 because there is scarcely any temperature difference between the courtyard and rooms. As a result, underground house in Matmata doesn't ventilate enough and this status needs to be improved by building a tower for ventilation. It might also be improved. In the case of Yao Dong in China, an improvement plan to install a ventilation pipe is examined for cancellation of ventilation disorder.

(3) Heating characteristics of soil

To know the thermal characteristics of the soil, a measuring device needs to be made along JIS A 1412-2[6] to measure heat conductivity. To make this device, a disposable pocket heater and a handy cooling pad were used as the heating board and the cooling board of the device shown in Fig. 22 and Fig.23. The sample was covered with insulation of 80 mm thick.

The value of 0.314 W/m^2 was measured in average. This value is close to the heat conductivity of the ocher from 0.36 to 0.3[7] W/m^2. This should be the heat conductivity of the oil used for the house. According to the Table 3, the measured value is much lower than any other sort of soil. It can be said the soil of Matmata hardly transfers heat and it is suitable material in the area of strong sun shin and high temperature.

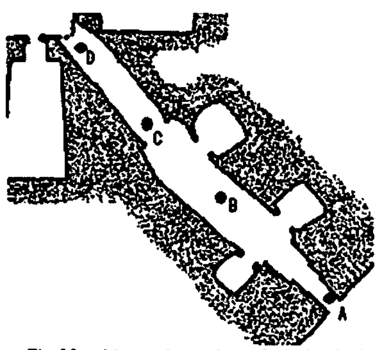

Fig.20 Measuring points of wind velocity

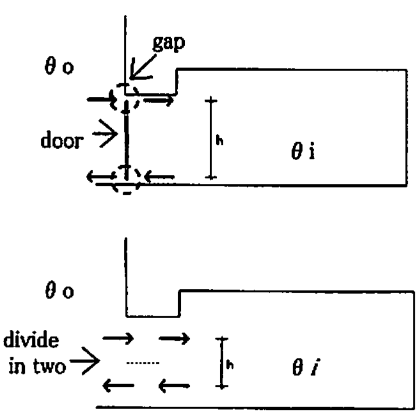

Fig.21 Models for calculation of ventilation

Table 2 Calculated ventilation rate

			kitchen	bedroom	children's	living room	safe
	h[m]	door closed	1.7	1.7	1.5	1.6	1.4
		door opened	0.9	0.9	0.8	0.8	0.7
	V[m³]		49.6	100.7	52.8	59.5	38.2
9:00	θo[℃]		24.9				
	θi[℃]		26.4	25.0	24.9	24.9	25.5
	ventilation [m³/h]	door closed	3.4	0.2	0.0	0.0	0.8
		door opened	192.3	13.3	0.0	68.8	43.8
	number [n/h]	door closed	0.1	0.0	0.0	0.0	0.0
		door opened	3.9	0.1	0.0	1.2	1.2
13:00	θo[℃]		36.5				
	θi[℃]		28.7	26.1	26.4	26.4	26.6
	ventilation [m³/h]	door closed	17.7	23.6	15.4	21.8	13.8
		door opened	992.1	1380.9	995.9	1154.1	719.7
	number [n/h]	door closed	0.4	0.2	0.3	0.4	0.4
		door opened	20.0	13.7	18.9	19.4	18.8
17:00	θo[℃]		30.1				
	θi[℃]		28.0	26.6	26.4	26.7	26.5
	ventilation [m³/h]	door closed	4.8	7.9	5.7	7.4	5.0
		door opened	267.8	490.8	364.8	388.1	261.8
	number [n/h]	door closed	0.1	0.1	0.1	0.1	0.1
		door opened	5.4	4.9	6.9	6.5	6.9
21:00	θo[℃]		25.1				
	θi[℃]		28.3	25.7	25.6	25.7	25.9
	ventilation [m³/h]	door closed	7.3	1.4	0.8	1.3	1.1
		door opened	407.6	79.8	49.4	68.7	58.3
	number [n/h]	door closed	0.2	0.0	0.0	0.0	0.0
		door opened	8.2	0.8	0.9	1.2	1.5

Table 2 Results of ventilation rate at the skifa

measuring time		9:00		13:00		17:00	
point	sectional area [m^2]	wind velocity	amount of ventilation [m^2/h]	wind velocity [m/s]	amount of ventilation [m^2/h]	wind velocity [m/s]	amount of ventilation [m^2/h]
A	3.5	1.8	22176.0	1.3	15750.0	1.0	12348.0
B	3.8	2.1	25957.8	0.9	11826.7	0.7	9901.4
C	6.3	-	-	0.6	12434.4	0.4	9495.4
D	4.2	1.0	14466.6	1.5	23146.6	1.0	14923.4
average			20866.8		15789.4		11667.1
air change [ach]			205.8		155.7		115.1

(4) Comparison to Yao-Dong

Yao Dong in China is the most similar type of underground house. Fig.24 and 25 are floor plan and section. Fig.26 and 27 are reports of thermal environment of Yao Dong by research group for Yao Dong in China on July 1986. [9] From the data of temperature and humidity, environment is similar to Matmata room whose atmosphere is stable all day. But room humidity is higher than Matmata, 75% in Yao Dong and 55% in Matmata. This was assumed related to rainfall. Although an annual rainfall is just 100 to 150mm higher than in Matmata, most of it falls in summer. Moisture of soil gets higher and then room humidity gets higher after all. From this comparison, Matmata environment is more comfortable than Yao Dong because of lower humidity and higher effects of thermal capacity of soil.

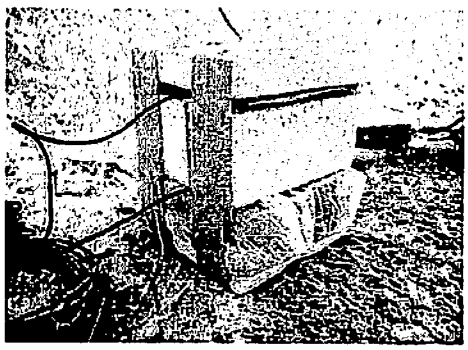

Fig.22 Instrument of measureing heat flow

Table 3 Heat conductivity of various soi

material	heat conductivity [W/m^2]
soil of Matmata	0.31
ocher[7]	0.36 ~ 0.38
soil(clay)[8]	1.50
soil(sand)[8]	0.90
soil(loam layer)[8]	1.00
soil(ashes)[8]	0.50

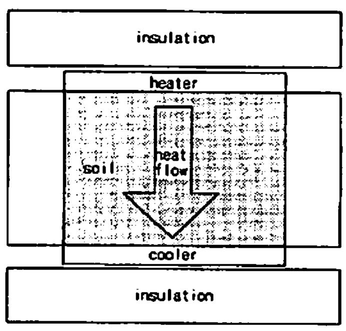

Fig.23 Diagram of measureing heat flow

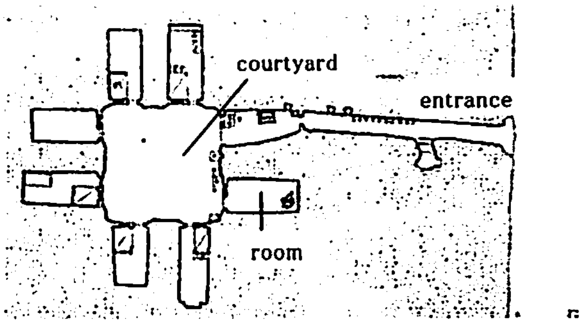

Fig.24 Floor plan of Yao Dong[9]

Fig.25 Section of Yao Dong[9]

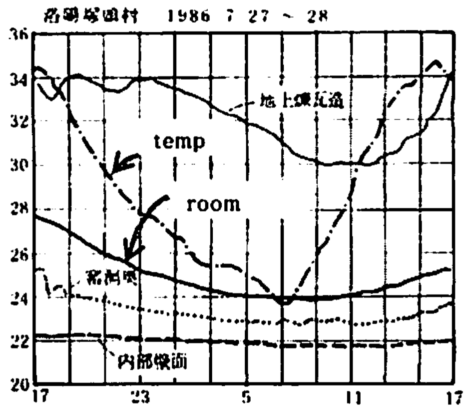

Fig.26 Outdoor temp. and room temp.[9] from previos survey on Yao-Dong

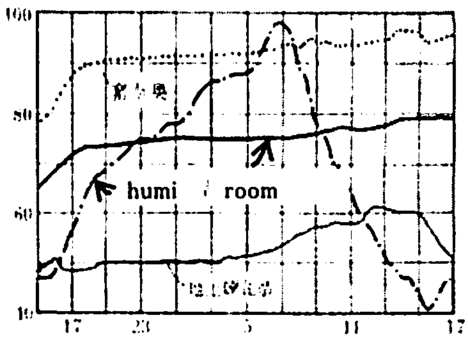

Fig.27 Outdoor humid. and room humid[9]

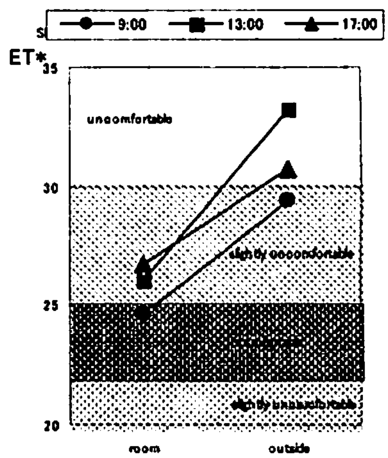

Fig.28 SET* of the underground house

6. Thermal comfort by SET*

In order to evaluate the comfort of Matmata underground houses on the basis of these results of the measuring, SET* is on of the most suitable methods. Criteria of comfort presented by A. D. McIntyre in 1890 was used.[10] Measured values were used for air temperature, mean radiation temperature (MRT), humidity, and wind velocity; and metabolism rate was assumed 1.0met and thermal resistance of clothes as 0.6clo to calculate the SET*. Data of 9:00, 13:00 and 17:00 on Aug. 24th were used and the areas were shed, children's room and living room. The SET* of inside was fixed as the average SET* of these three rooms, and was compared with SET* outside of the house. Fig.28 shows the results of the calculation. In the room was comfortable or slightly uncomfortable at any time. On the other any time; therefore, in the room is much more hand outside the house was virtually uncomfortable at comfortable than outside the house. At 13:00 and 17:00, SET* outside became lower together with temperature, while SET* in the room became higher. This is because that heat of the rooms was difficult to radiate and that the heat stored in the soil made the room temperature and average MRT higher.

As above mentioned, it was proved that underground house in Matmata had a character of constant temperature; therefore, underground house was proved to be very effective to live a comfortable life under the awfully hot climate of Matmata.

7. Conclusion

After consideration based on the measurements in Matmata, where temperature is very high and humidity is low, it is most important to make use of characteristics of soil and raise the effects of constant temperature. Then it is possible to get a comfortable living space in such hot air climate. When temperature is 37℃, room temperature is 26℃, and when temperature is 17℃, room temperature is 25℃. Also, room temperature hardly changes all day, so room thermal environment is more comfortable than outside on the ground. Heat conductivity of soil is 0.314[W/m^2]; therefore, soil of Matmata hardly transfers heat. In this circumstance, it is very effective to have a living space under the ground, but it is hard to get enough ventilation in the rooms. When the doors are closed, ventilation rate is 0.2 to 0.3 [n/h] at noon and 0 to 0.2 at night. When the doors are open, it's 13 to 20 [n/h] at noon and 1 to7 [n/h] at night. As residents gather in room mostly at night, it is necessary to invent a means to improve this ventilation problem.

Acknowledgements

The authors would like to appreciate to the occupants for measurements, and also to the conductor.

This study depends on the Academic project of laboratory of Eco-history, Graduate School of Hosei University, and on Grant-in-aid for scientific research of the Ministry of Education, Culture, Sports, Science and Technology, Japan.

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