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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

(巻 / Volume)

43

(開始ページ / Start Page)

27

(終了ページ / End Page)

34

(発行年 / Year)

2007-03

(URL)

<https://doi.org/10.15002/00003743>

Thermal and Air Environments on Cave dwellings in Cappadocia, Turkey

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This paper deals with the field measurements on thermal and air environments of cave houses at Cappadocia, Turkey. The authors carried out the measurements of the traditional cave dwellings of three types existing there, and the temperature and humidity, the globe temperature, the wall surface temperature are measured. After these measurements, in the traditional cave typed dwelling, the indoor temperature remained between about 25 degrees against 35 degrees in outdoor temperature, in the condition of a door open. Especially, in the room which does not face directly outside, the temperature is approximately constant with 17 degrees Celsius. It is correspond to "cool" as a SET* zone even in the summer. The Cave dwellings restrain an influence of a high temperature and strong sunlight in summer.

Keywords: Vernacular, Cave house, Field measurements, Cappadocia

1. Introduction

Turkey is located in contacts with the Asian west end and the European east end, so that both Asian and European cultures have been developed. There are a lot of cultural and historical inheritances in Turkey. Besides, in central Anatolia, the soil is eroded for long time and makes strangely shaped rocks and, creates the nature scene that it is extremely unusual. It is assumed that there have been many cave dwellings and underground cities dug the shaped rocks in Cappadocia area. This is the reason that Christians escaped from persecution of the other believers.

Caver houses are protected from strong sunlight and a dry high temperature climate of the summer, and also from a severe low temperature for winter. In other words it is a house of a peculiar form, but it would be good choice from the view point of environmental engineering.

In this paper, surveys on thermal environment of summer on cave houses existing in Turkey Cappadocia, and environmental characteristics were analyzed.

2. Climate of Cappadocia

Cappadocia is located in about 200km southeast from the Capital Ankara as shown in Fig 1, a plateau area of a step type climate of about 1,200m meters above the sea level. The average climate of the moon highest temperature up to 31 degrees Celsius in summer, and is dry with 470mm of an annual precipitation.

Volcanic ashes fell by eruptions of volcanoes of Mt. Erciyes and Mt. Hassan, hundreds of millions of years ago, and were piled up in this local whole area. In long-time, the soil has been eroded by rain and wind, and ravine and a rock peak create the unique scenery as shown in Fig 2.

Cappadocia cave is authorized by UNESCO for world heritage (a compound inheritance) in 1985.

It is assumed that Christians dig a hole of house to the earth and strangely shaped rocks from the fourth century and came to live, and it is also assumed that there were not only cave type houses but also large-scale underground cities, shown in Fig. 3, at the time in the sixth century, to escape from a particularly Arabic Muslim.



Fig.1 Map of Turkey



Fig.2 Whole aerial view of Cappadocia

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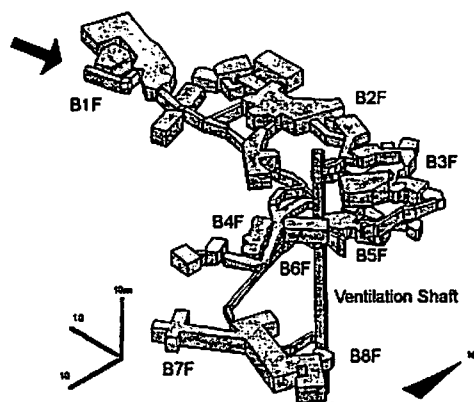


Fig. 3 An example of underground city [1,2]

3. Underground city

In Cappadocia district, there have been large-scale underground towns which are carved out of the relatively soft tufa. The main reason of the existence for these towns was that Christians escaped from persecution from a Muslim, in the sixth century. The number assumed to be exceeded over 300. Kaimakuli and Delinkuyu are the typical underground cities. It is assumed that 3,000 and 10,000 people lived there, respectively. Delinkuyu underground city extends to eight levels of basements and has a ventilation shaft, penetrating eight level floors. The underground town is easily accessible from the corresponding towns above.

4. Mushroom type Rock

There are a lot of mushroom-shaped strange rocks in many places in Cappadocia. The process these rocks were formed are shown in Fig. 4 and Fig. 5. Lava from a volcano is piled up to 100-150m on the upper part of the land. They consist of the tufa layer of a light color with upper parts of hard basalt.

Water such as rain finds a flow way naturally at a plateau slope and come to carve the stratum, and is easy to erode (II in Fig. 4), and turn to the mushroom-typed rocks (III) and cone type (IV) which a firm part of basalt of the outer layer appears in the shape of a hat became form.

5. Uchisar

There are some rocky mountains in Cappadocia district, Uchisar is situated at the highest point in the region. Uchiisar is a meaning such as three fortresses.

Uchisar is dotted with cave houses in cone type rocks at the traditional city side(Fig. 6), and box type houses built in halfway up the mountain in the new city side (Fig. 7). There is no resident now in these cave houses in the old city side. They have been used for nests of doves until 50 years ago, since habitants left there. A dove was not edible but used feces as fuel.

6. Cave house in the cone typed rock

6-1 Outline of the house

The cave house in a mushroom-typed rock for the measurement is located in the old village in Uchisar. Fig.8 shows the plan and Fig. 9 – Fig.12 show the outside view,

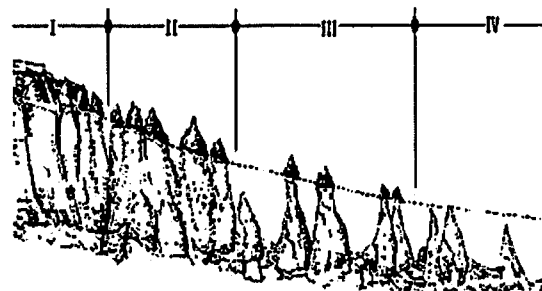


Fig. 4 Process of the rock erosion [3]



Fig. 5 Eroded rocks



Fig. 6 Uchisar in old city side

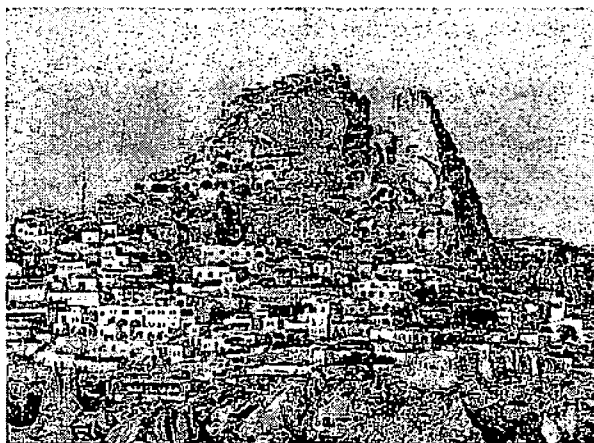


Fig. 7 Uchisar in new city side

respectively.

The western part of the rock is used mainly for the shop, cafeterias and guest rooms for the tourist (Fig. 12), and eastern part is used for the residence (Fig. 11).

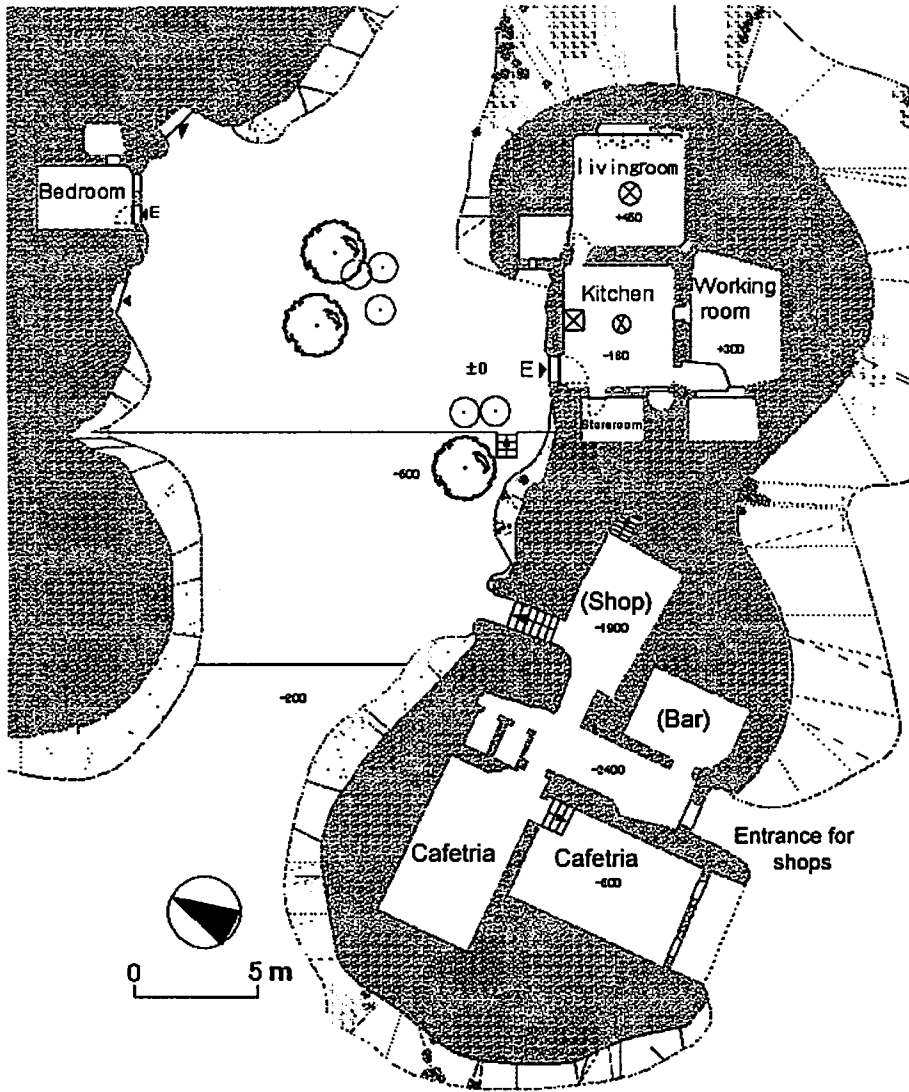


Fig. 8 Plan of the traditional cave house



Fig. 11 Outside view
A: Entrance
B: Small window of the kitchen
C: Outlet of exhaust for the furnace



Fig. 12 Entrance of the shop, cafeterias



Fig. 9 Outside view of the cone type rock of



Fig. 10 North view of the cave house

The padrone of this house, a person of around seventy years old, said that his family lived in this house, and he was born and grew up here.

6-2 Outline of the measurements

The residence cave for the measurement consists of three rooms: a kitchen, a working room for winery and a bedroom, as shown in Fig. 13 to Fig. 15. The work room is for manufacturing wine, because wine is one of the big industries in Cappadocia district.

The kitchen and the living room have a small window for lighting and a furnace on the floor. The kitchen has a small exhaust duct on the ceiling that became black with soot of fire. The floor and wall of the kitchen are of skin of the rock, but those of the living room are covered with carpets.

The measurements of thermal environment were carried out on these three rooms and a bedroom in the other side of the rock. The room temperature, the globe temperature, and wall surface temperature were measured, from August 6 to 9, 2006.

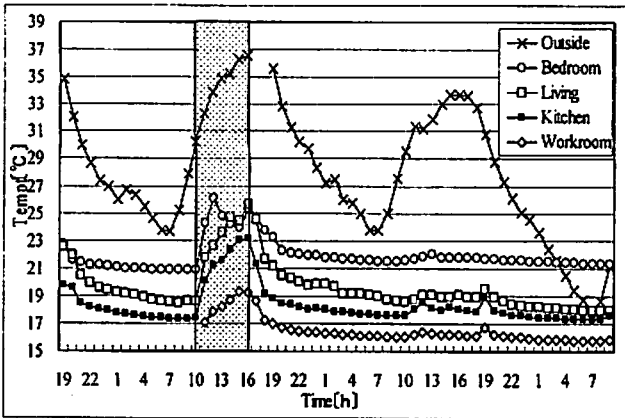


Fig. 16 Outside and room temperature
 [shaded area] : condition of door open

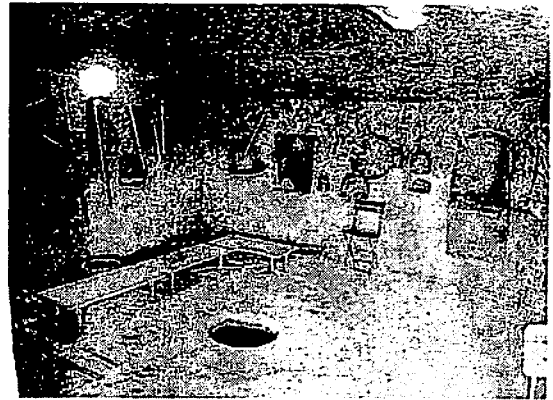


Fig. 13 Kitchen Living room

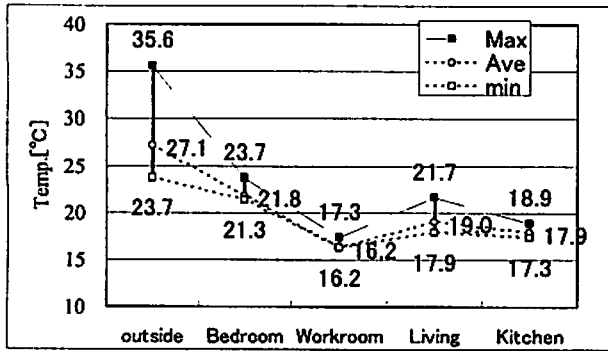


Fig. 17 Changes of outside and room temperature

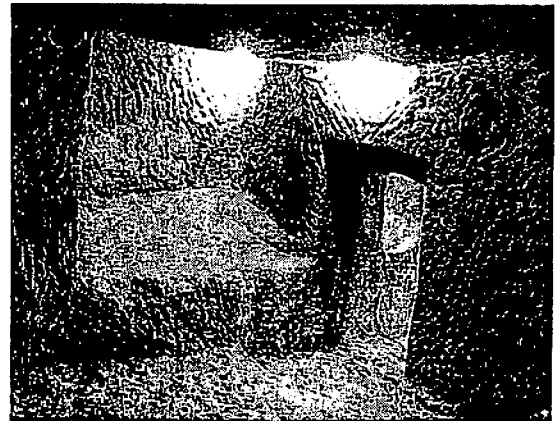


Fig. 14 Work room for winery

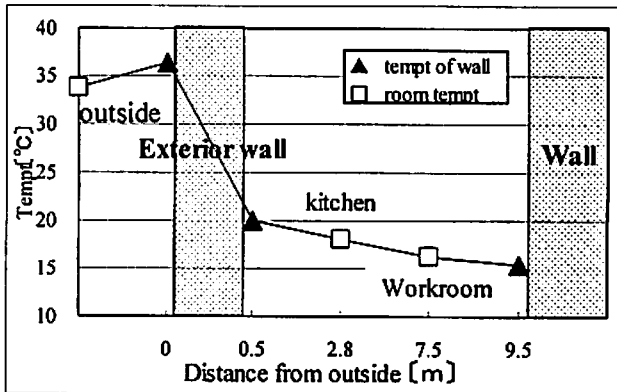


Fig. 18 Relation between temperature and distance from outside



Fig. 15 Bedroom, covered with carpets

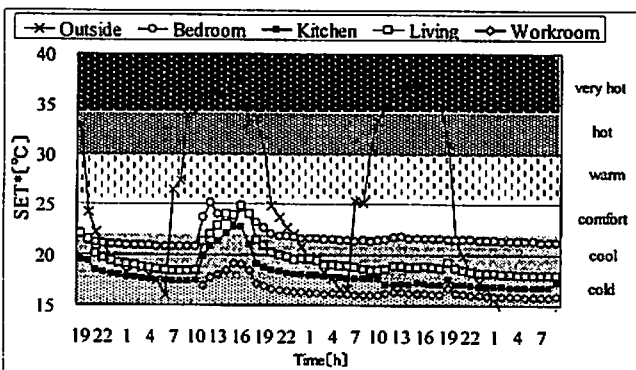


Fig. 19 SET* of the rooms in the cave house

Outside temperature and humidity, solar radiation, and wind speed were measured at the summit of the eastern neighboring rock. Unfortunately, because the anemometer was broken by someone, the data of after August 7 lack of wind speed and wind direction.

6-3 Results of cave house

Fig. 16 shows the results of temperature. The outside temperature reaches to the maximum value of 36.6 degrees Celsius from minimum 23.6 degrees C. However, indoor temperatures of the bedroom, the living room, kitchen and work room are stable less than about 23 degrees C, under the door closed condition: as the case except a screen tone zone in the figure. The temperature in the bedroom changed highest about 36 degrees C, and it falls by the order of the living room and the kitchen, and work room. The temperature of work room was the lowest of the rooms, and it is almost stable about 16 degrees. The maximum width of temperature change in each room is shown in Fig. 17, the value of the work room is

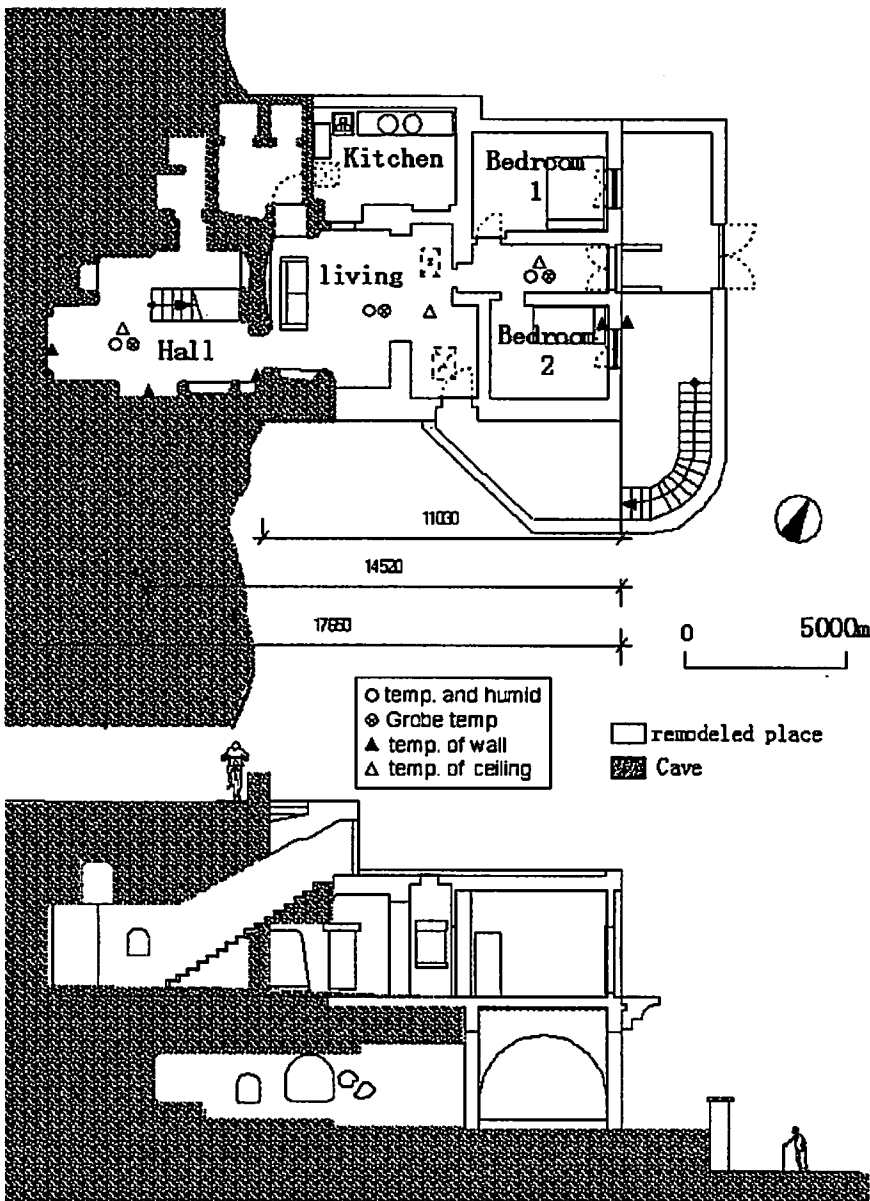


Fig. 20 Plan and section of combination house

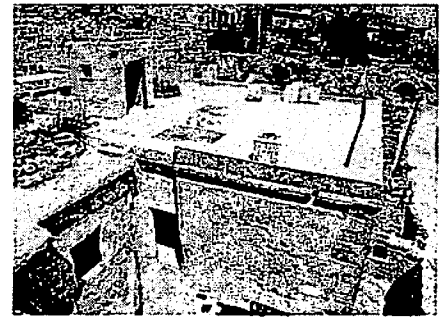


Fig. 21 Entrance



Fig. 22

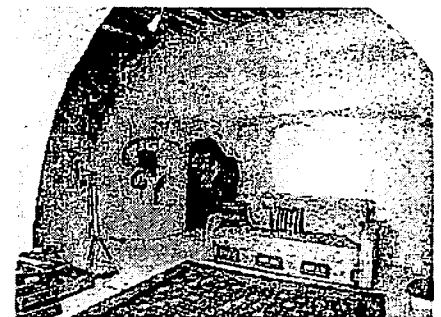


Fig. 23

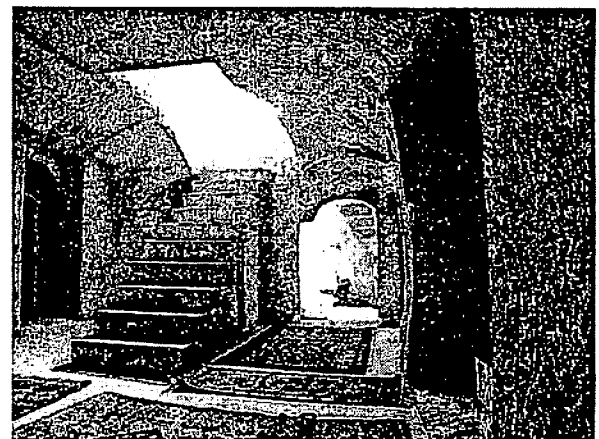


Fig. 24

very small. One of the main reasons that the temperature changes little and is low with around 16 degree is that the surface wall of the work room is about 15 degree, shown in Fig. 18. In Fig. 18, measured on August 8, the outside surface temperature of the external wall rises to 36.3 degrees C with the strong sunlight. But, the values of the inside are almost below 20 degree. That is the characteristics of temperature stability of the rock soil.

In the condition of the door open, in the screen tone area in Fig. 16, the room temperatures rise, but, even in the kitchen, the temperature rises little, and remains below around 23 degree.

6-3 SET* of the cave house

The results of SET* was calculated as in Fig. 19, based on the measured values. Outdoor SET* reaches the range "hot" or "very hot" in the daytime. On the contrary, indoor night-time SET* is evaluated in the range of "cool" - "cold", by the reason of constant temperature characteristics of the soil. It remains in the range of "comfort" in the condition of door open in daytime. This is influence by the cold radiation from the cave surface.

Above all, it is remarkable that the soil works as the cool

storage. The cave house is convenient to get cool against the climate of high temperature and strong sunlight in Cappadocia.

7 Combination house with cave and modern

7-1 Outline of the combination house

The combination house for the measurement is consist of the cave dug on the hillside and the box typed rooms, shown in Fig. 20. Photos are shown in Fig. 21 to Fig. 24. The repair by a resident and his friends has been carried out before long time also during the measurements. The original entrance was on the first floor, but now, the inhabitant accesses from the roof. The hall around the stairs is originally a cave place. This is the coldest place in the house. The living room may originally be a half open space and is bright by sunlight from the skylight. The bedrooms are of modern house, facing to the East. The first floor remains as old days and is not yet repaired.

7-2 Outline of measurement of the combination house

The surveys of the environment were carried out by measuring the room temperature and humidity, globe temperature, outdoor temperature and humidity at height of 1.5m, from August 9 to 12, 2006. Measuring points are also shown in Fig. 20. Outside temperature and humidity were measured at the roof.

7-3 Result of the combination house

Fig 25 and Fig. 26 show the result of the temperature and humidity. The outside temperature reaches the maximum value of 35 degree August 10. The temperature in the bedroom changes approximately in the same way as the outdoor temperature as for the early time of the morning; but is lower than that from the latter half of the morning to afternoon, because the bedroom faces the east. The indoor temperature of the living room does a similar change with that of the entrance hall, but it is 4 degree higher against that of the entrance hall. The entrance hall is a traditional cave room, so that the entrance hall is cooled by the cold wall.

The outdoor relative humidity varies from the minimum value of about 15% to the maximum value of about 40%, shown in Fig. 26. The value of the entrance hall is relative high and it reaches to the maximum of 64 %. Humidity in the living room kept about 30% in daytime.

Fig. 27 shows the temperatures, at 6:00 and 16:00, as a function of the distance from the outside wall. In the house, the wall surface temperature lowers depending on the depth from the outside wall. Although the outer surface temperature indicates 33 degrees at 16:00 and 21 degrees at 16:00, the inside surface temperature is a range of 26 and 28 degrees. It is guessed that the thermal insulation of the wall is high.

Fig. 28 shows the results of SET* calculated by the measured data. The outside SET* varies in the evaluation range of "very hot" in daytime and "cold" in the midnight, shown in Fig. 28. Evaluation of three kinds of rooms is clearly classified as follows:

The entrance hall is a range of "cool" because of the advantage of the cave room. The bedroom ranges "warm" except the midnight besides it is made of modern type and sunlight enters well through a window faces the east. The living room, where the family gathers most, is in the range of "comfort". But it is in the range of "warm" in daytime, the ventilation may be required.

From the observation of the indoor wind movement, the cool draft from the entrance hall flowed in the vicinity of the floor of living room, though the warm air sometimes entered

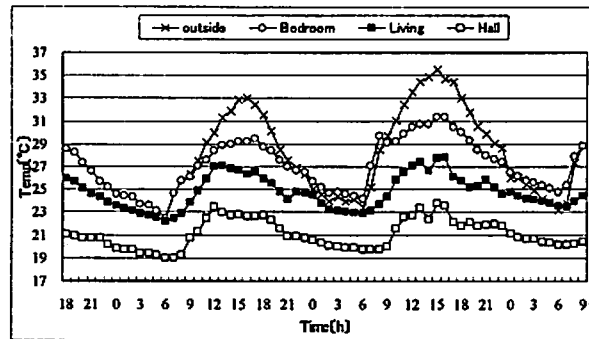


Fig. 25 Changes of temperature in combination house

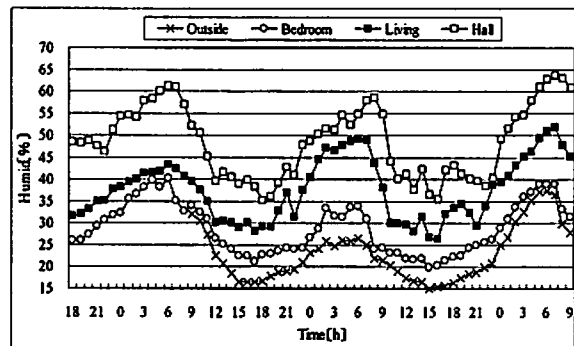


Fig. 26 Humidity in combination house

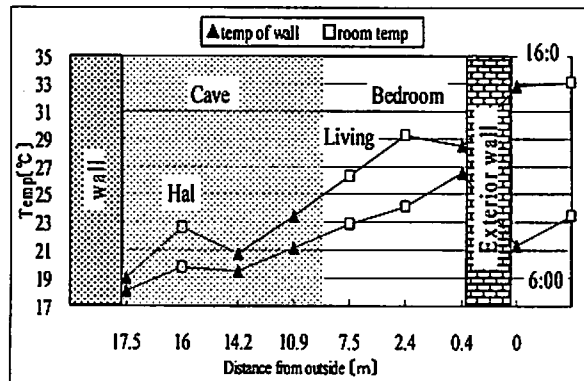


Fig. 27 Relation between wall temperature

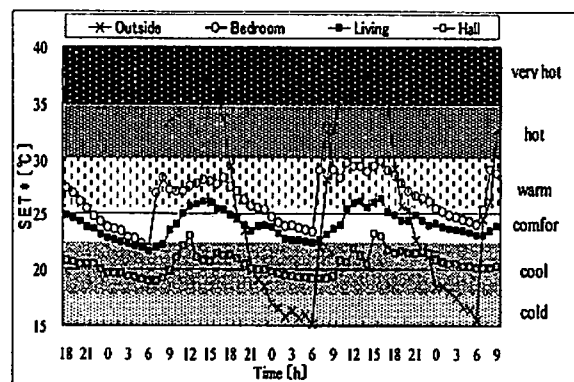


Fig. 28 Result of SET*

to this living room from a door of the neighboring door. Therefore it was comparatively comfortable because cold wind from an entrance hall drifted in the vicinity of a floor.

8. Modern house

8-1 Outline of the modern house

The modern house for the measurement is located around 1km from the old city side of Uchisar. It is made of tufa stones blocks with two story, and has a multipurpose open terrace on a attic. The measurement was carried out in the second floor rooms from August 7 to 9, 2006.

The size of tuff block is 170 mm×290 mm×620 mm, the wall is consist of double blocks with the width of 390 mm. The slave is used by concrete and the roof is made of wood. A sun panel for hot water supply is installed on the roof. It seems to be effectively using solar energy. Four families live there: a couple, a child, and a mother of the couple.

The measurements were carried out in the living room, a bedroom and a garret. The indoor temperature and humidity, the globe temperature and wall surface temperature are measured. During the measurement, only one wind was open in each room.

8-2 Result of modern house

The outside and indoor temperatures are shown in Fig. 31. Outdoor temperature reaches the highest of 36.6 degrees, and the lowest of 23.6 degrees. The temperature of a garret varies almost the same as the outdoor temperature. On the contrary, the temperatures of the living room and bedroom are almost constant around 28 degrees to 32 degrees, although only one window was open. It is thought that the doubled wall has enough insulation and thermal capacity.

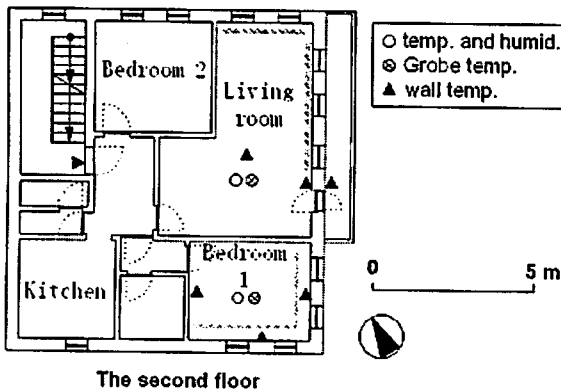


Fig. 29 Plan of the modern house

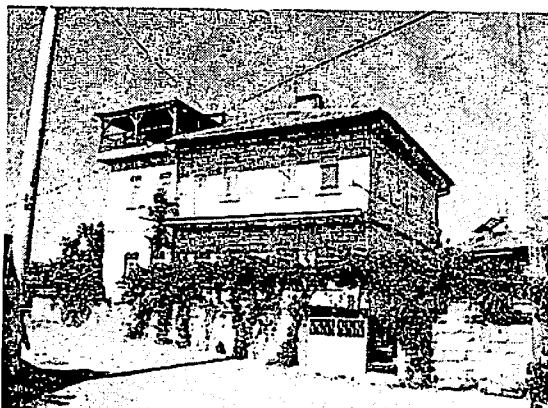


Fig. 30 East view of the modern house

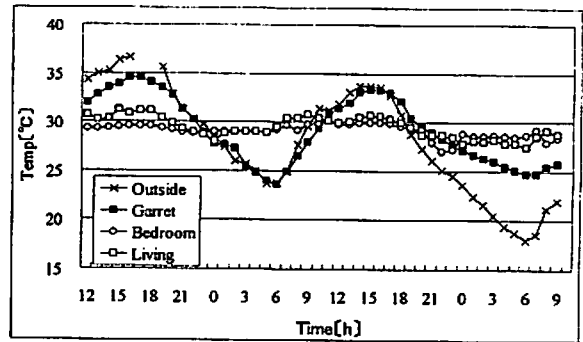


Fig. 31 Temperature of the modern house

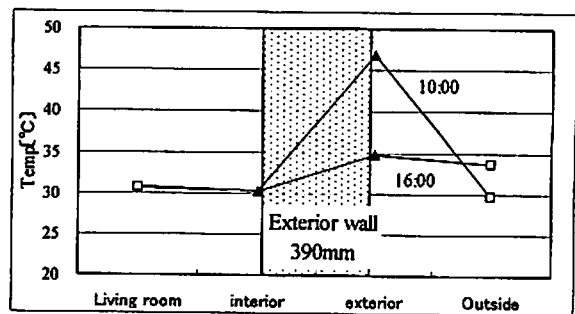


Fig. 32 Difference of wall surface temperature

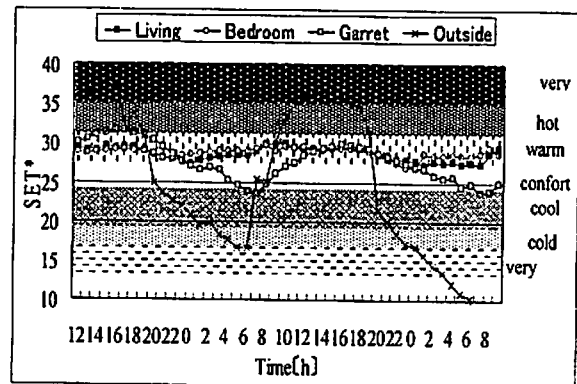


Fig. 33 SET* of the modern house

Fig. 32 shows the surface temperature between the exterior wall of the living room. The outside surface temperature reaches 47 degrees by the sunlight, because the wall is facing to the east. But the inside surface temperature remains about 30 degrees. This is right proof of the wall, the thickness of 390mm, having enough thermal insulation characteristics.

SET* evaluations are shown in Fig. 33. As having mention before the outside SET* varies from the range "cold" in the night to "very hot" in daytime, SET* does not change very much. It is remarkable that the bedroom is evaluated within the range of "comfort" to "warm", even without air-conditioning equipment.

9. Conclusions

The authors carried out the measurements of the traditional cave dwellings existing in Cappadocia, Turkey. The temperature and humidity, the globe temperature, the wall surface temperature are measured in three different type houses. After these measurements, the knowledge is obtained as follows:

- 1) In the traditional cave typed dwelling, the indoor temperature remained between about 25 degrees against of 35 degrees in outdoor temperature, in the condition of a door open.
- 2) Also in the traditional cave house, the temperature of a back room (a wine factory) is almost constant around the value of 17 degrees Celsius.
- 3) In the combination house with the cave and the modern masonry, the relation between the wall surface temperature and the distance from the outdoor wall is well correspond.
- 4) The modern house with double tuff masonry wall has sufficient thermal insulation and thermal capacity.
- 5) Above all, the cave house is a environment friend one with a underground room as a vernacular architecture against hot and strong sunlight weather of summer in Turkey.

Acknowledgements

The authors express great thanks to Dr. Shuzo Murakami, Professor of Keio Gijuku University, and Ms. Izumi Hosoe and Mr. Yusuke Shimazaki, Graduate Students of Keio Gijuku University with a great cooperation through this study. For investigation in Turkey, the authors also would

like to appreciate to the families who offered an investigation house: Mr. and Mrs. Ismail Kutougun; Mr. and Mrs. Murat Sumber; Mr. and Mrs. Nage Sari. In the whole stay in Turkey, Mr. Erisin Ok, an interpreter, took care of us over the official and private matters.

The authors express will of thanks to all the members concerned.

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