THE EFFECT OF SURROUNDING GROUND CONDITIONS AND VENTILATION RATES ON THE INTERNAL ENVIRONMENT OF TRADITIONAL EXCAVATED DWELLINGS IN SANTORINI, GREECE

K. Tsikouris[1], A. N. Young[1]

[1]The Bartlett, Faculty of the Built Environment, UCL, UK

ABSTRACT

This paper deals with the internal environment of traditional excavated dwellings in Santorini and the effect the conditions of the surrounding volcanic rock have on it. Three buildings were monitored in the summer and winter and the results of the monitoring were used to simulate the natural ventilation of the dwellings and calculate the amount of moisture which is released from the porous material of the walls. The study shows that the internal high relative humidity values are mainly due to this moisture release. Simulation shows that the installation of a moisture barrier and an increase of the ventilation rate provides comfortable conditions in the summertime, whereas reduction in the ventilation rate and some additional heating is required in the winter. This study finally proposes a calculation method for the required ventilation rate based on a fixed temperature profile for the house, which can lead to the development of a management system to control the environmental conditions indoors.

KEYWORDS

Modeling, Moisture, Natural Ventilation, Outdoor Air, Relative Humidity.

INTRODUCTION

There have been many studies on the thermal and moisture movement behaviour of conventional building materials and contemporary methods of construction but not many on traditional materials and methods. The case of the vernacular excavated buildings on the island of Santorini is an example of traditional architecture from which designers can learn the benefits of the use of natural materials and passive design. The volcanic rock which have covered the island during the successive explosions of the adjacent volcano supplies a firm and stable, yet easily worked, material for excavating dwellings. The thermal mass of the surrounding ground guarantees a stable internal temperature, but the lack of cross ventilation and the humid climate often produce high relative humidity in the internal spaces. Although the high levels of humidity in the ambient air in Santorini and the cool internal conditions within the excavated dwellings would be expected to lead to high relative humidity, it was felt that release of moisture from the volcanic rock played a major part in determining the overall internal humidity. The aim of this study therefore is to show that release of moisture from the walls does indeed play an important part in determining the overall humidity conditions. Another aim is to show that if the moisture release from the walls can be controlled with the use of a vapour barrier the ventilation rate will only have to increase in a few cases in order to maintain acceptable humidity levels. This study attempts to contribute to the understanding and solution of the environmental problems associated with these traditional buildings, their refurbishment and any similar dwelling constructed in the future.

METHOD

The Case Study Buildings

For the purposes of this project, three vernacular buildings on Santorini were selected for study. The houses monitored are representative of the basic excavated building typology to be found on the island. They were selected from the many traditional houses available, not all of which, however, were suitable for monitoring. Some buildings were damaged during the 1956 earthquake and deserted, while others had been restored by tenants, with their initial construction and form alternated by installing new sealed windows and doors, building new partitions or removing existing ones. The houses chosen have all maintained their original layout with the least possible damage or alteration to the original materials and architectural elements.

The Study Design - Methodology

The buildings were monitored over a period of one week each, both in the summer and winter. To assess the thermal and moisture performance of the vernacular buildings and the behaviour of the volcanic rock, the following monitoring method was implemented. "Smart Reader"[1] data loggers were used to monitor the environmental conditions of the air within and outside the dwellings, set to record readings for temperature (°C) and relative humidity (RH - %) at a sample rate of 20 minutes. For the wind velocity, spot-measurements were taken manually four times a day with the use of an E.T.A. 3000[2] hot wire anemometer.

The monitored data were then used as input values to the computer simulation software, BREEZE 6.3[3], to model the natural ventilation of the buildings and determine the ventilation rates for each of them. The results of this simulation for Dwelling A are presented in Figure 5 (dotted line) and can be used as an interpretative tool to assess the effectiveness of the ventilation of the buildings. They are also used in later stages of this study, to provide the air change rate (ACR) for further calculations.

The next step was to calculate the moisture release from the building envelope with the use of the set of equations which is described in the following section. Then the assumption was made that the moisture release from the surrounding ground was halted by means of a vapour barrier placed on the internal wall surfaces of the houses and the resulting internal RH was calculated. The values derived from this calculation and the monitored temperatures are the predicted internal conditions after the barrier is installed. These conditions were then compared to the acceptable environmental conditions, as presented on the psychrometric chart. Not all the sets of figures satisfied the thermal comfort conditions and, therefore, desirable values were chosen for the temperature and RH. These values were used to predict the required ACR to maintain acceptable conditions within the dwellings.

Calculation Procedure - Equations

The following equations were used for the balance between the external and internal moisture, and the calculation of the moisture released or absorbed by the walls.

---

[1] Smart Reader is a registered Trademark of Status Instruments LTD
[2] E.T.A. 3000 is an Airflow Developments product
[3] Breeze 6.3 was developed by the Building Research Establishment, Garston, UK

At any point in time, the moisture in the internal air of the dwelling is made up of that brought in with the fresh air, plus that released from the walls, plus that produced from other internal sources, less that taken out by the ventilation air as it leaves the dwelling. Averaged out over time, the overall moisture transfer into and out of the building has to reach an equilibrium, such as to satisfy the following equation:

$$M_{GEN} + (ACR \times MC_{EXT}) + M_W = ACR \times MC_{INT} \quad ...(1)$$

where M_W is the moisture released from the building's envelope in g/h, MC_{INT} is the moisture content of the internal air in g/kg of dry air, MC_{EXT} is the moisture content of the external air in g/kg of dry air, ACR is the ventilation rate in kg/h and M_{GEN} is the moisture generated by people, appliances and household activities in g/h, as estimated from tables in [1].
If we rearrange equation (1) the moisture released or absorbed by the walls is

$$\mathbf{M_W = [ACR \times (MC_{INT} - MC_{EXT})] - M_{GEN}} \quad ...(1.1)$$

The initial hypothesis was that the high values of RH are largely due to the moisture release from the walls. In order to show this effect assume that a vapour barrier is installed on the internal wall surfaces of the dwellings. The internal moisture content and, consequently, the internal RH will change. Since there is no longer moisture released from the walls, the moisture equilibrium in equation (1) will now be expressed as:

$$M_{GEN} + (ACR \times MC_{EXT}) = ACR \times MC_{INTB} \quad ...(2)$$

and

$$\mathbf{MC_{INTB} = MC_{EXT} + \frac{M_{GEN}}{ACR}} \quad ...(2.1)$$

where MC_{INTB} is the internal air moisture content with the barrier installed, in g/kg of dry air.
For the calculation of the moisture content (MC) and the RH and the respective conversions between the two, the following general equations were used.
The moisture content of the internal and external air is given by the following formula in [2]:

$$MC = 622 \times \frac{VP}{BP - VP} \text{ g per kg of dry air} \quad ...(3)$$

where BP is the barometric pressure in Pa and VP the actual vapour pressure in Pa, given by

$$VP = \frac{RH \times SVP}{100} \quad ...(4)$$

where SVP is the saturation vapour pressure in Pa for the temperature at that time [1].
And if we rearrange equation (3) and substitute into equation (4), RH is given by

$$RH = \frac{100 \times BP \times MC}{SVP(MC + 622)}\% \Rightarrow \mathbf{RH = \frac{10132500 \times MC}{SVP \times (MC + 622)}} \quad ...(5)$$

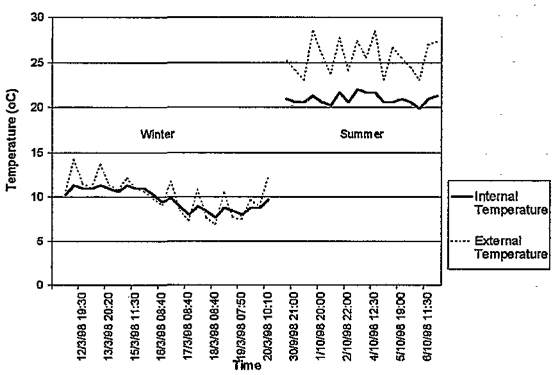

Figure 1. Temperatures in Dwelling A

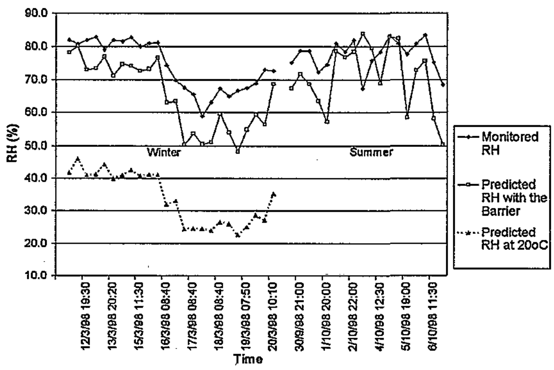

Figure 2. Relative Humidity in Dwelling A

RESULTS

The results of the monitoring study are presented in the graphs. Figure 1 shows that the high thermal mass of the ground is advantageous to the buildings in terms of temperature stability, especially in summer, when the internal temperature was very stable and took values within the acceptable range for thermal comfort. The RH, however (Fig.2), is high most of the time. That could be caused either by the external moisture content being higher than the internal, in which case the RH inside is driven by the external air, or by excessive moisture produced indoors. In most cases the external moisture content given from (3) with actual RH values was found to be lower than the internal (Fig.3). It appears, therefore, that significant quantities of moisture are released inside (Fig.4) and the ventilation is not enough to cope with it.

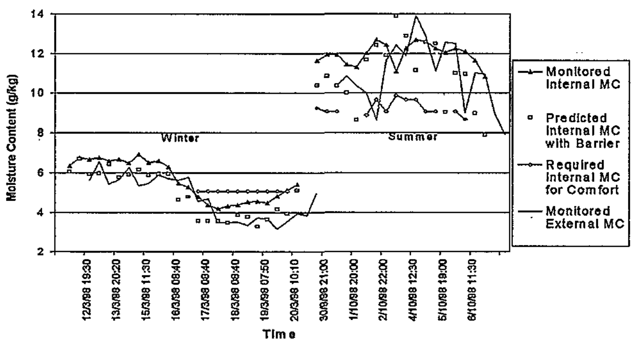

Figure 3. Moisture Content in Dwelling A

With the assumption that a vapour barrier is placed on the wall surfaces, the resulting RH was predicted from (2.1) and (5) to be in most cases significantly lower than the monitored one (Fig.2). This fact alone supports the hypothesis that the high RH indoors depends largely on the moisture release from the walls (Fig.4). However, even with the moisture release from the walls reduced to the minimum, some of the RH values are still high. It should be noted, however, that no heating was applied to the houses. Although the internal summer temperatures are very good in terms of thermal comfort (Fig.1), the winter temperatures are very low indeed. Assuming that the houses are heated in winter to 20°C by means of electric heaters or a balanced flue gas boiler, there will be no further moisture generation indoors. The new RH can be calculated at this temperature from (5). Comparing the results of this calculation to the ones before heating (Fig 2), not only has the RH largely reduced, but in some cases excessive dryness might occur in the winter.

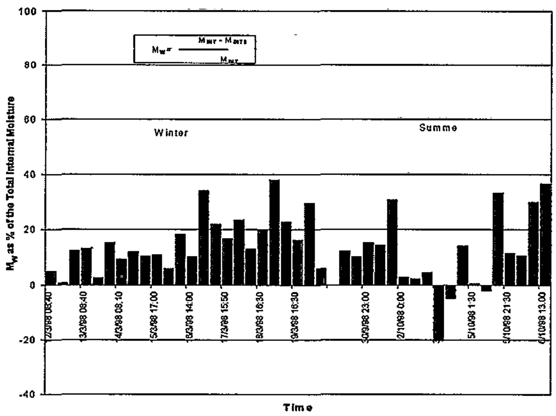

Figure 4. Contribution of the Walls to the Overall Moisture Content

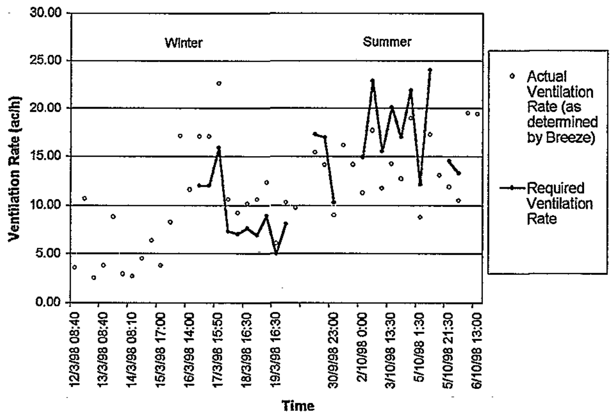

Figure 5. Ventilation Rates in Dwelling A

After the RH was computed with the moisture barrier installed on the walls and the temperature raised to 20°C, its values were compared to the acceptable range of RH values for thermal comfort, as this is presented in the psychrometric chart [3] and modified for applications in Greece in [4] and [5]. In the case where the RH value fell outside this range, a desirable value from within the range was chosen. Both values, the actual and the desirable, can be expressed in units of absolute moisture content. Since it is assumed that the external conditions remain unchanged, equation (2) can be expressed as

$$M_{GEN} + (ACR \times MC_{EXT}) = ACR_{ACT} \times MC_{ACT} \qquad \ldots(6)$$

and

$$M_{GEN} + (ACR \times MC_{EXT}) = ACR_{REQ} \times MC_{REQ} \qquad \ldots(6.1)$$

where ACR_{ACT} is the actual ventilation rate in kg/h, ACR_{REQ} is the required air change rate in kg/h, MC_{ACT} is the actual internal moisture content in g/kg of dry air and MC_{REQ} is the required internal moisture content in g/kg of dry air.

By transposing equations (6) and (6.1) the required ventilation rate is

$$\mathbf{ACR_{REQ}} = \frac{\mathbf{ACR_{ACT} \times MC_{ACT}}}{\mathbf{MC_{REQ}}} \qquad \ldots(7)$$

Figure 5 (in which the solid line represents the required ventilation rate) indicates that in the summer an increase in the ACR is required to reduce RH to comfort levels, whereas in wintertime the ACR in many cases has to be reduced. This would in turn be beneficial for the energy consumption for heating, since less cold external air would be introduced and the heating energy required to maintain the air temperature to 20°C would be reduced.

DISCUSSION

It is evident from the above that the environmental conditions of the surrounding ground have a major impact on the internal environment of the traditional excavated dwellings in Santorini. The thermal mass provides temperature stability and cooling in the summer, but not adequate heating in the wintertime, especially when the ventilation rate is high. In addition the volcanic rock into which the dwellings are curved, is a porous material with high moisture conductivity, causing instability in moisture content and RH. This study showed that the walls release large amounts of moisture most of the time, but also absorb moisture when the moisture content (hence the vapour pressure) outside is greater than the one indoors. Reducing this moisture transfer is essential for the achievement of comfortable indoor environmental conditions, however other measures may also need to be taken, such as to increase or reduce the ventilation rate, to approach better conditions over a longer period of the year.

In this study some assumptions had to be made, leading to some uncertainty in the results. For example the numerous assumptions made in BREEZE 6.3 and the estimation of the moisture generation from people, appliances and household activities may lead to a degree of uncertainty. However, given the indicative nature of the work, the accuracy is considered to be adequate for this empirical approach to the importance of the surrounding ground conditions to the internal environment of the excavated dwellings.

CONCLUSIONS

The main disadvantage of the internal environment of the traditional excavated dwellings in Santorini is their unstable moisture movement behaviour, usually indicated by high RH values. A continuous exchange of large amounts of moisture occurs between the porous ground and the internal air. This results on the development of high moisture content and RH, especially when the interior of the dwellings is not heated. As it was shown by this study, the installation of a vapour barrier in most cases reduces the RH, but it is not always enough. Additional heating is usually required in the winter, whereas in many cases the ACR has to be increased in the summer or redused in the winter, in order to achieve acceptable conditions. Further work needs to be done on the control of the ventilation of the dwellings responding to the needs indicated by this study, with a control system which senses temperature, RH and wind speed. It should be possible to develop a management system that would control the ventilation and produce desirable internal conditions.

ACKNOWLEDGEMENTS

The authors wish to thank the Graduate School of UCL for their financial aid to this study.

REFERENCES

1. British Standards Institution, 'BS 5250: British Standard Code of Practice for Control of Condensation in Buildings', Rev. Ed., BSI, London 1989
2. Jones, W.P., 'Air Conditioning Engineering', 3rd Edition, Edward Arnold, London 1985
3. Givoni, B.,'Man, Climate and Architecture',Applied Science Publishers Ltd, London 1976
4. Kolokotroni, M., 'The Building Bioclimatic Chart: Modification for Application in Greece', *Technika Chronika – A*, Greece, 1991, Vol. 11, No 4
5. Kolokotroni, M., Young, A., 'Guidelines for Bioclimatic Housing Design in Greece', *Building and Environment*, Vol. 25, No 4, 1990, p. 297-307
6. CIBSE Guide, 'Volume A: Design Data', The Chartered Institution of Building Services Engineers, London 1986