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AN INVESTIGATION INTO THE VENTILATION AND THERMAL PERFORMANCE OF CONTEMPORARY HOUSING IN NORTH AFRICA

Mohamed B. Gadi and Ian C. Ward
Building Science Unit
School of Architectural Studies
University of Sheffield
Sheffield
S10 2TN
UK

ABSTRACT. New housing developments in North Africa often show very little regard for local culture, climate and geographical resources. Evidence has indicated that these new houses consume large amounts of energy to maintain indoor thermal comfort or as is often the case have excessively high internal air temperatures.
In order to be able to design better housing a deeper understanding of the thermal performance is required. One way of doing so is to carry out computer simulations based on a validated computer programme of the proposed design.
This paper outlines a method of establishing the likely indoor air temperatures of a proposed design using local climatic data and a new approach to establishing the likely air change rates resulting from an understanding of the occupancy patterns within the house.
The ventilation aspect of this paper is perhaps the most important as it involved the testing of the proposed design for the house in a boundary layer wind tunnel to obtain the actual variation in internal static pressures between the different rooms.
This variation was then converted to air change rates by using the actual external pressures and the air transfer areas.
Having established the variation in air change rates throughout the day a computer simulation was carried out using a standard thermal admittance programme and local climatic data.
The results were then checked against independently published work on the indoor air temperatures found in housing in the City of Ghadames, Lybia and good agreement was obtained.

1. INTRODUCTION

Most residents throughout the North African region, particularly the older generation, still hold the view that the traditional house is thermally more satisfactory than the contemporary house.
One of the reasons for this dissatisfaction is that the traditional house was constructed of local materials such as rammed earth, puddled mud, lime, straw and palm leaves which gave the house a high thermal mass which prevented a rapid build up of temperature in summer and kept the house warm in winter. The contemporary house on the other hand is constructed of lightweight concrete or burnt clay blocks which have little thermal mass thus allowing heat to pass through readily. One other factor which affects the resultant internal air temperature of such housing is the ventilation rate. In such climates during summer it can be too hot to open windows during part of the day as the resultant ventilation rate would heat the house further. In traditional housing which was designed on an inward looking concept a courtyard was provided in which there was a fountain, grass and shaded by a veranda. This architectural form produced a cooled enclosure in summer and as most of the windows opened onto this courtyard natural cooling of the air was produced. In winter when the air was cooler, the high mass of the veranda floor (which was constructed of stones held in place by lime morter) was warmed by the sun which produced a warming effect to the air before it passed into the house.
On the other hand the contemporary house is designed on a more outwardlylooking aspect with more windows exposed to the external environment. This has the effect of making the rooms on the perimeter of the house very hot under certain summer conditions and the result is that the only cool area in the house is the centre core. By adopting such a plan form the centre core becomes the main living space in summer and in winter when ventilation is needed cross ventilation is promoted by the plan form, Fig. 1.

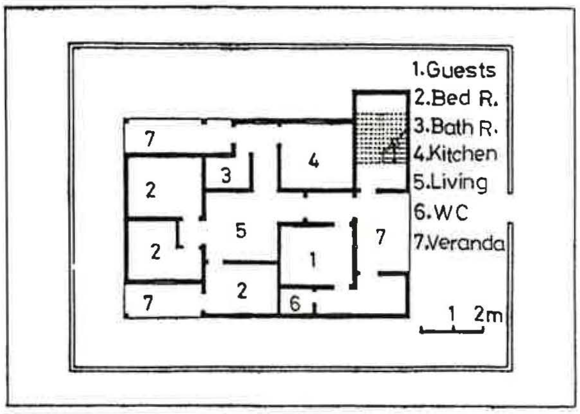

Figure 1: Contemporary North African house plan.

The traditional house could not offer the scope for housing the domestic appliances which go hand in hand with modern life, such as refrigerators, furniture etc. Thus people accepted the new house type despite it's poor thermal performance.
Due to this situation, it has become the feeling among the local population that an alternative house, designed and built with respect to local climate, culture and modern life styles is needed. This is not an easy task because of the lack of local design criteria and local design codes. Most of the design codes which are available are derived from foreign sources without particular reference being made to local conditions. In order to overcome these obstacles and to arrive at relevant solutions designers have two alternatives, either:-
(a) To develop a new version of the old courtyard house.
(b) To investigate the thermal characteristics of the current house in order to improve its performance.
One method of investigating the performance of a new house design is to carry out a series of computer simulations. However in order to do so it is necessary to have available appropriate climatic

data as well as a knowledge of the thermal properties of the building materials. Perhaps the most difficult data to obtain are the wind forces acting on the proposed building. As these are used to generate the pressure differences across the building and hence the natural air change rate it is very important that the correct values are used. There are several techniques for predicting ventilation rates through naturally ventilated buildings, some of which have been discussed by Gadi /1/. However, for the purpose of the present study, it was concluded that scale model techniques were more convenient than other techniques such as computer simulations or full scale techniques.

2. SCALE MODEL STUDIES

2.1 Experimental Set Up

In this technique, a prototype scale model of the proposed building was constructed and mounted in a boundary layer wind tunnel where the appropriate external wind environment characteristic of a particular type of terrain was simulated in order to investigate the resulting dynamic and static pressures of wind outside and inside the building.
The tests were carried out in the University of Sheffield 1.2 x 1.2m Boundary Layer Wind Tunnel. The simulation arrangement of the rural boundary layer and the details of the wind tunnel are given by Lee /2/. A general view of the flow simulation arrangement and the layout of the building model are shown in Plate 1.

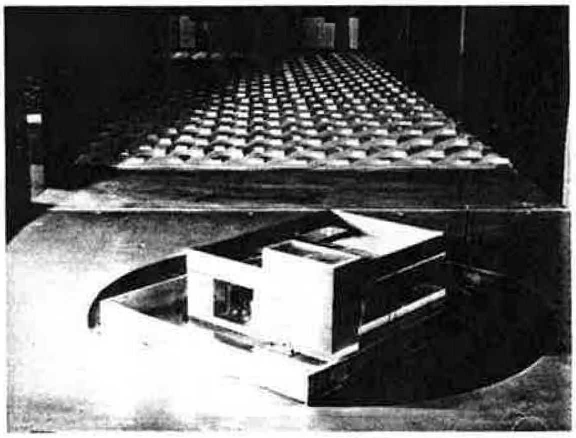

Plate 1: The rural Boundary Layer arrangement and the building model in the Wind Tunnel.

The mean wind velocity profile for the rural simulation measured at the turntable centre shows a maximum free stream velocity of 9.3m/s which was attained at a height of 800mm, the physical thickness of the boundary layer. The mean velocity profile plotted in its power law form, shows that the best fit line through the data points has an exponent of $\alpha = 0.19$, /2/. Accepted values for rural terrain lie in the range of 0.14 to 0.17 however a value of $\alpha = 0.19$ is given by ESDU /3/ for a similar type of terrain. Applying these exponents within the power law for the standard meteorological height of 10m:-

$$V_{10}=V_{300}(10/300)^{0.19} = 9.3(10/300)^{0.19} = 4.9 \simeq 5\text{m/s}$$

$\alpha = 0.14$, $V_{10} = 5.8 \simeq 6$m/s, 300m is the gradient height for rural terrain. These two values agree well with the measured mean monthly wind speeds recorded at airport sites for three locations in Libya, Tripoli, Bengazi and Sabha, Table I.

Table I: Frequency of wind speed intervals.

m/s	1-1.5	2-3	3.5-5	6-8	9-11	11-17	calm
Tripoli	4.2	14	35.4	30.6	10.0	0.8	5.0
Bengazi	5.9	13.8	34.9	29.3	9.7	0.1	6.3
Sabha	9.9	20.2	26.6	22.0	12.0	1.0	8.3

Once the rural boundary layer has been simulated inside the wind tunnel, the next step was to model the building to fit in the tunnel's working section. In a paper published by Aynsley /4/ he discusses the different modelling parameters for boundary layer wind tunnel studies of natural ventilation, and highlighted the importance of the blockage ratio.
The wind tunnel blockage is the ratio of the cross-sectional area of the model to that of the working section. Actually there is no fixed criteria for this ratio and the main requirement in this aspect is to keep the model as small as possible. However it is generally recommended to attain the blockage ratio below 5%, Lawson /5/. In the present work, the maximum blockage ratio for the model employed was 2.4%. This was due to the suitable scale, 1:50 of the model which allowed for the important architectural details of the building to be modelled. This scale was also convenient for the technique used in the pressure measurements, Plate 2.

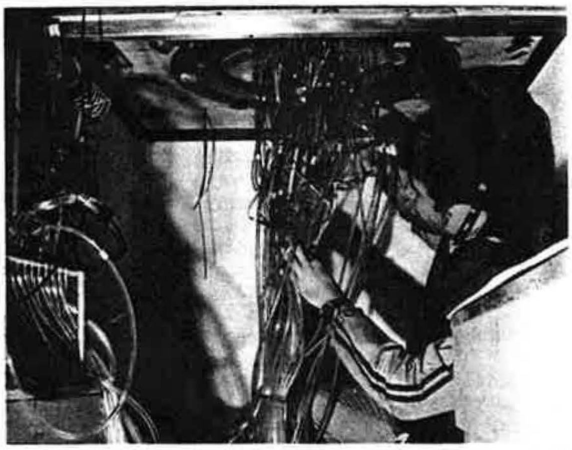

Plate 2: Plastic tubes connected between individual pressure tapping and measuring devices.

It has also kept the resulting Reynolds number within the acceptable range, 3.6×10^6, which is at the upper limits of the critical value (10^5, 3.6×10^6) given by Melaragno /6/, above which the air flow is expected to be turbulent. Generally, it is well known that buildings with sharp edges can be modelled and tested in the wind tunnel as they will give the same flow patterns for a range of air speeds.
The model was made of two materials, aluminium plate and perspex. The choice of the aluminium was due to the need for a sharp edged model with smooth surfaces in order to define the flow separation points at the corners. As it was useful to provide a visual access through the model, both the floor and the roof were made of perspex which is a transparent material.
One limitation associated with this material is that it needs extra care in order to avoid any cracks or scratches on its surface.

2.2 Tests Carried Out

Having modelled the building and its wind environment, the following stage was to prepare the

model for measuring wind pressure distribution on its envelope and through its plan for eight wind directions and according to different configurations of doors and windows. The main purpose for conducting these tests was:-
To predict the air change rates under various patterns of using doors and windows by the local people.
The model employed had eleven cells laid in a generally rectangular plan, Fig. 1. It is surrounded by a solid fence of 2 cm high and at different distances from its sides. All external and internal doors were made openable from thinner aluminium plates and the joints around them were filled with a coat of vaseline in order to control their movement and to avoid overscaling of the joints. Windows were used either fully opened or closed with aluminium plates. External pressure measurements were taken through a linear grid of pressure tapping fitted at the window centre line. Later on, another grid was constructed on the floor of each cell for the measurement of internal pressure, Plate 3.

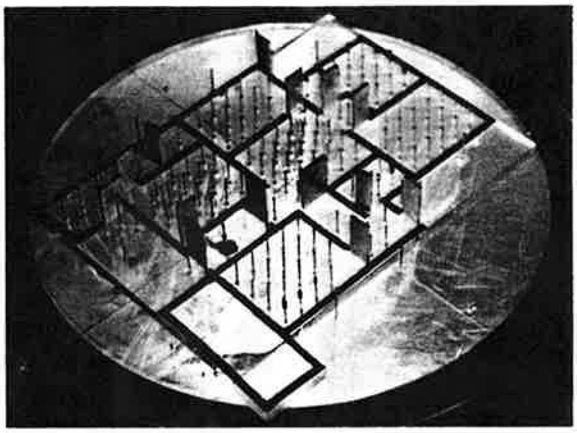

Plate 3: Plan of the building model and the pressure tapping distribution.

In order to ensure maximum accuracy in the pressure measurements and to prevent any leakage of air from one cell to another through joints between walls, floor and roof, all these joints were sealed with vaseline.
After measuring the external pressure, the following series of pressure tests were carried out internally but according to the daily patterns in which doors and windows are usually used by the local people of North Africa influenced by their social and climatic environment. Therefore the following cases were considered:-
- A summer day or a winter night. All external and most internal openings were closed.
- A summer night (bedtime) or a winter day. All external and most internal doors were closed while all windows were opened.
- A summer night.(before bedtime). All internal doors and windows were opened while external doors were closed.
- A hypothetical case in which all openings were opened.

Finally all pressure readings were obtained from a digital micromanometer linked to a 20 channel scanning box. The reference velocity pressure was checked by a pitot tube mounted inside the wind tunnel at a height of 800 mm (the gradient height).

3. PREDICTION OF VENTILATION RATES

After knowing the pressure distribution inside and outside the building, it became possible to identify the different paths and directions in which air will flow through the building bearing in mind that it flows from higher to lower pressure regions.
The consequent step was then to calculate the rates of air entering and leaving the building through and around its openings in order to estimate the resulting air change rates. By studying the plan of the house in question, it can be seen that it is made up of two adjoining apartments; the family zone and the guests zone, between which the only access is through the entrance corridor which is controlled by a swinging door in the middle. When the rates of air flow through each zone were calculated separately, it was found that significant differences exist for all cases and under most wind directions. The mean minimum and maximum air flow rates through the family zone were respectively 0.07 and $1.5m^3/S$, for the first and fourth cases of occupancy paterns mentioned previously. The corresponding values for the guests zone were 0.03 and $1.15m^3/S$.
When the first case was taken as the "Reference Case" in which the minimum rate of air flow ($0.07m^3/S$) was associated with a minimum "Leakage Area", ($0.3m^2$) then all the rates of air flow and their corresponding leakage areas were related to the reference case, a clear relationship was obtained.

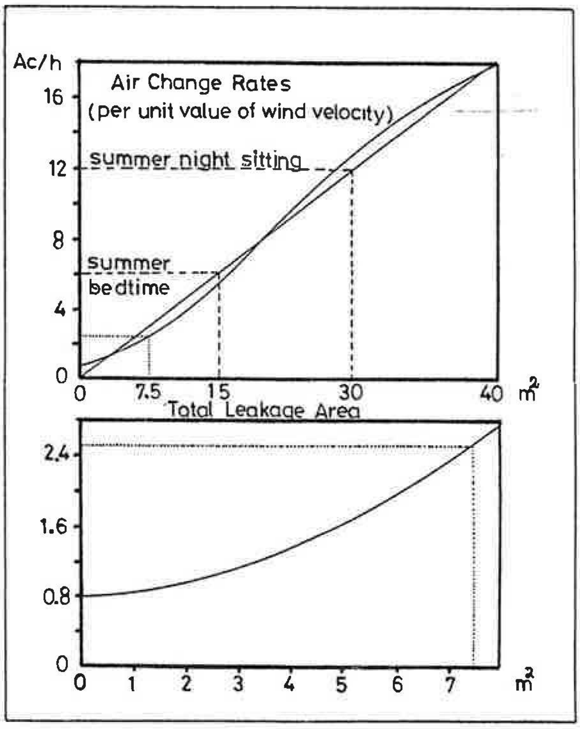

Figure 2: Ventilation Rate versus Leakage Area.

On the other hand, when the resulting rate of air change for the present house (in which the family zone has a space volume of $300m^3$) was plotted against the total leakage area for the four cases, almost a linear relationship was produced , Fig. 2 . If the total leakage area together with the average on-site wind speed are known at any period of occupancy, the resulting rate of air change can be obtained by multiplying the average wind speed by the rate of air change (per unit value of wind velocity) corresponding to the total leakage area presented in Fig. 2. This graph was used to predict the air change rates for various periods of occupancy related to the typical patterns of domestic life in most parts of the region of North Africa, Table II.

Table II: Environmental data (Sabha)

Time	Air Temp (°C)		S.W.Rad. (W/m^2)		Wind (m/s)		Vent. (Ac/h)		Casual Gains (W)
	Jun	Jan	Jun	Jan	Jun	Jan	Jun	Jan	
2	24.9	5.7			2.2	2.0	12	2	350
4	23.5	4.6			1.2	1.9	12	2	350
6	24.0	4.0	122		2.4	3.7	12	2	700
8	28.2	6.4	491	130	3.1	3.0	3	8	700
10	34.7	13.9	841	353	3.6	2.6	3	8	140
12	37.6	17.8	986	453	3.8	3.5	3	8	140
14	39.0	19.5	841	353	3.7	4.1	3	8	2380
16	37.6	18.7	491	130	4.4	3.5	3	8	575
18	32.7	14.1	122		3.9	3.2	3	8	575
20	29.7	10.7			2.5	2.7	20	4	1190
22	27.8	8.6			1.5	2.3	20	4	1075
24	26.5	7.0			1.9	2.9	12	2	350

4. CALCULATED AND MEASURED INDOOR AIR TEMPERATURES

The predicted ventilation rates together with assumed casual heat gains and measured local climatic data, Table II, averaged over fifty years, were used within a validated computer programme based on a standard thermal admittance procedure, /7/, to calculate air temperatures inside the contemporary house employed in this study, Fig. 3.

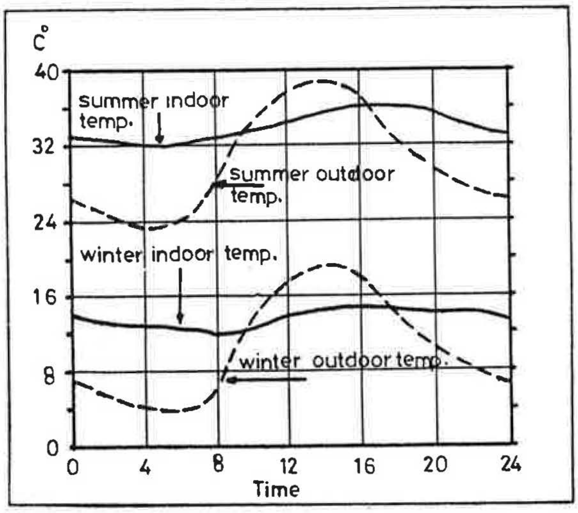

Figure 3: Indoor and outdoor air temperatures for January and June in Sabha.

The climatic data was recorded at a meteorological station in Sabha, (27°00 N, 14°:26E). A comparison with similar data for four other locations in the region, Ghadames, Aswan, El-Cufra and In-Salah, /1/, has shown slight deviations from one another due to differences in altitude and distance from sea.

In a paper published in 1985, Ahmed et al /8/ presented the results of full scale thermal simulation of typical traditional and contemporary houses in the city of Ghadames (30°00 N, 9°:50E). The new houses of Ghadames are of single and double storey detached from each other and built according to the same design and construction concepts of the house tested in the present work.

In the results presented in Ahmed's paper, the summer ambient air temperature in Ghadames varies from 22 to 40°C with an average of about 31°C. On the other hand, the average indoor air temperature in the new house is 35°C and ranges between 34 and 39°C for July-August. The new house reduces the ambient air swing of 18°C to 5°C.

In the present study, the estimated average indoor air temperature for June is 34°C ranging from 32 to 36 in Sabha. Thus the swing in air temperature is reduced from 15 to 4°C. The winter ambient air temperature in Ghadames varies from 4 to 23°C whilst that of the new house ranges between 12 and 14°C in December. In the present work the estimated indoor air temperature for the new house ranges between 13 and 15°C in January.

5. CONCLUSIONS

This investigation has provided building designers with a simple design tool they need to produce the actual daily ventilation rates which are likely to occur inside contemporary houses in North Africa. The provision of such data would make it possible to carry out realistic thermal simulation of any house design for any location in the region. Preliminary simulation of the expected indoor thermal conditions of a particular design is a necessary and important step towards improving the building's thermal performance. The comparison with the results of the full scale experimental observations in Ghadames has emphasized the validity of the information produced in the present study. However, both investigations have illustrated, in terms of air temperature, the poor thermal performance of the new house in comparison with the well known better thermal performance of the old traditional house. An apparent limitation of the present work is that it does not cover a wide range of house designs. This actually is not a significant factor as most house plans in North Africa are based on similar design concepts influenced by almost the same cultural, climatic and geographical environment.

6. REFERENCES

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