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SIMPLIFIED COMPUTER-AIDED BUILDING DESIGN FOR PASSIVE INTERNAL TEMPERATURE MODERATION IN HOT-ARID CLIMATES

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ABSTRACT

Computer program TAD (Thermal Architectural Design) which was developed by the authors to design buildings in which the temperature is controlled passively, is applied to study the courtyard house in hot arid climates. The computer program determines the maximal and minimal interior air temperatures, is simple to use and very inexpensive to run. It was found that building orientation has negligible effect on interior temperatures, which are reduced as the court house's height increases, as its walls thicken, and as the longwave emittance of its exterior surfaces increases. The major heat loss mechanism was found to be longwave radiation from these surfaces. Having a larger exterior surface, which is partially mutually shaded, the court house was thus found to have lower interior temperatures than a box-shaped house of same volume.

1. INTRODUCTION

The most fundamental variables to be considered during the thermal design of a building which is supposed to provide a comfortable interior climate with minimal use of hardware and purchased energy, include the building's geometry (including openings), orientation, exposure, surroundings and construction materials (including treatment of outside surfaces). These constitute the "most passive" elements of any passive heating or cooling system that may be contemplated for the building as a next step. To achieve a design which is economically, technically and esthetically optimal, the selection of these variables must have a good quantitative basis. Normally, manual calculations are too complex, and available simplified guidelines would be inadequate when more than a single building type or climate need to be considered.

Although a number of comprehensive computer programs are available to assess the thermal performance of buildings (cf. [1-4]), they are fairly complex and expensive to use, particularly when a relatively large number of different cases need to be evaluated. Except for [1], they also do not include adequate consideration of shading effects. Consequently, and in view of the renewed energy consciousness of building customers and designers, a simpler method and computer program were developed [5,6] to serve architects and other building designers as a convenient tool for the determination of the thermal performance of buildings which do not utilize HVAC equipment, and it includes appropriate consideration of shading effects. Being easy to use and having a low computation cost, the program¶ constitutes essentially an interactive computer-aided design tool. The inputs consist of the description of the building's geographic location, orientation, geometry, envelope, construction and color, and adjacent ground reflectivity, as well as local atmospheric conditions and ambient temperature, humidity and wind speed. The basic outputs are the maximal and minimal interior air temperatures during the test period (periods of 12 hours were used, in single or consecutive fashion), which are used as the only comfort zone index in the existing model. More detailed results on temperatures and heat fluxes through each building surface can also be obtained as output, if desired. The architect can thus vary the input parameters and evaluate their influence on the comfort zone index, which is the output. Based on this output, he can continue varying the parameters till operation within the comfort zone range (say, 20°C to 30°C in the hot-arid zones) is arrived at and is compatible with other considerations such as esthetics and economics. Apart from supplying quantitative design information about the comfort attributes of the building, this interactive procedure enhances creativity and educates its user.

As a specific example, the design of buildings for hot arid climates was studied, to achieve interior comfort conditions with no air conditioning equipment. The basic concepts of dwelling design under these circumstances have been known through the history of mankind, and have progressively moved from the qualitative to the quantitative stage (cf. [7, 8]). The newly developed computer program was applied specifically to the courtyard house. The courtyard has been a dominant feature of houses in the hot arid zone since the early days, achieving vernacular status.

An interesting court house design, developed in the 1940's to improve the living conditions of peasants in Upper Egypt, is shown in Fig. 1 [9].

Apart from providing such benefits as privacy and security (cf. [10]), the court house provides improved environmental comfort, mainly by its

¶Named TAD: Thermal Architectural Design

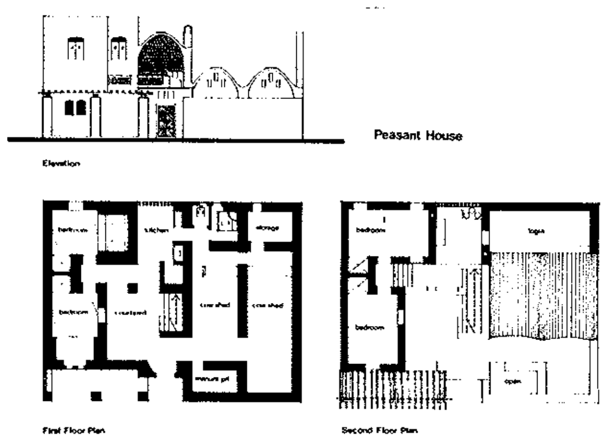

Fig. 1. Experimental courtyard house for peasants at the New Gourna village, Upper Egypt [9]

inherent control of radiative effects (cf. [11]). Usually having minimal openings on the outside periphery, it has its windows and doors open into the court. If designed properly, the court and its peripheral walls are shaded most or all of the day, thus preventing direct solar radiation gain to its own ground and to the building's court-facing walls. Overnight, however, and even during the day when the atmospheric humidity is low, the courthouse geometry exposes a large surface to the sky, thus allowing a large thermal (infrared) radiant loss from the house. Program TAD was developed to include the quantitative determination of transient mutual shading and radiant heat loss and gain effects, and is thus well-equipped to handle the court house study. In addition to providing practical court house design recommendations, the study investigates in detail the transient heat flow in and out of the building and thus explains the natural cooling mechanisms.

2. THE HEAT TRANSFER MODEL

The major objective of the heat transfer analysis in TAD is to determine the maximal and minimal air temperatures in the investigated building, as a function of building variables and climatological parameters. For that purpose, a simplified method was applied using the Total Thermal Time Constant concept which was developed and experimentally confirmed by Hoffman [12]. Subroutines calculating temporal solar incidence angles on the various building and adjacent ground surfaces and determining the size and location of all shaded areas [13] were used in conjunction with the site's latitude, and temporal ambient temperature, humidity and wind velocity to supply the necessary inputs to the heat transfer model. The program is applicable to any building shape and skin composition, and can be used for any site on earth. At present, it does not include the effects of interior ventilation. The program is described in detail in [5,6]. For the present study, several modifications were made in the computer program which was described in [5].

3. COURT HOUSE COMPUTATIONS AND RESULTS

3.1 Model Definition

The general shape of the court house studied is shown in Fig. 2.

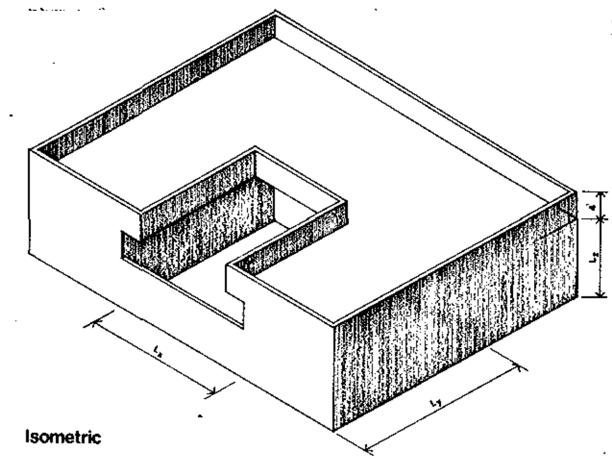

Fig. 2. Isometric view of the court house model

Further invariant dimensions of the house, and the numbers defining the different house and surrounding ground surfaces considered in the analysis are shown in Fig. 3.

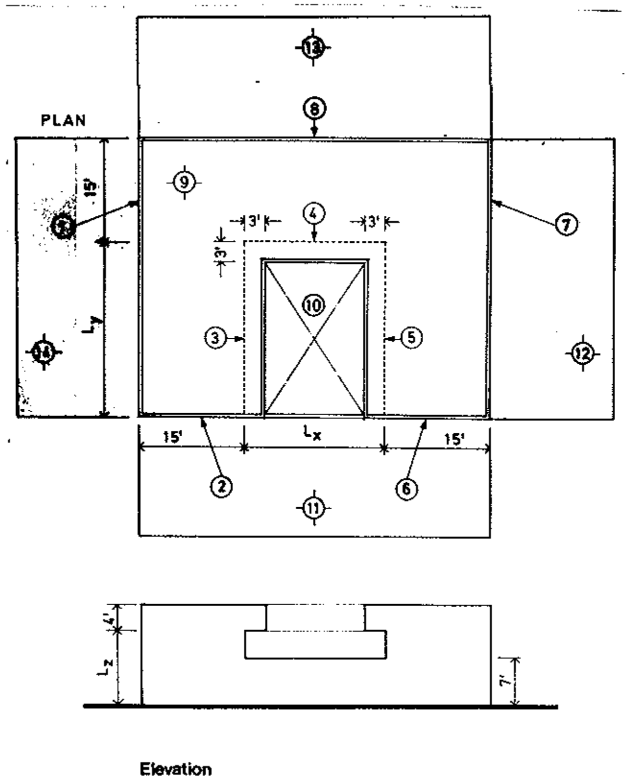

Fig. 3. Drawing and surface numbers of the court house model. Gray areas indicate ground surfaces considered in the model.

The method of analyzing the house's thermal performance was to define a "base configuration" and then to change one variable at a time while keeping the rest at the "base configuration" values, and to examine the interior air temperature extrema and the heat fluxes and shading patterns on each house surface. The base configuration is defined in Fig. 3 and Table 1.

Variable	Test Range in [6]
Court width L_x = 6.10 m (20')	6.10 - 15.25 m
Court depth L_y = 7.62 m (25')	7.62 - 16.77 m
Building height L_z = 6.71 m (22')	3.35 - 12.81 m
Wall thickness t_w = 43 cm for south east & west walls (mainly brick)	43
= 28 cm for north wall	28
Roof thickness t_r = 27 cm (mainly concrete)	27
Radiative properties of building surfaces:	
Emittance = 0.9	0.9
Absorptance = 0.25	0.12 - 0.4
Reflectance of ground cover r = 0.2	0.2 - 0.6

Table 1: Definition of court house model's base configuration and the range of variables studied in [6]

3.2 The Present Study

The present study extends the tests of [6] to include the influence of wall thickness, exterior surface emittance, a winter day, and the influence of 24-hour meterological conditions on the extrema of the interior air temperature. It also attempts to explain the reasons for the results obtained, mainly by analyzing the detailed heat flux and temperature data obtained. To demonstrate the thermal advantage of a court house over a house without a court, computations were also made on a cube-shaped house with the same volume, height and using the same materials as the court house.

Typical computer-plots of the hourly shading are shown in Fig. 4. As expected, the northern orientation exposes less of the court to sunshine than the southern one. The increased shading of the court for a taller building is also seen when comparing the third column (from the left) to the ~~first.~~ second.

For the configurations tested, the house's court-facing walls were always entirely shaded, so that the radiation striking their surfaces was composed of the diffuse insolation component and of solar radiation reflected from the court. Noting that the exterior net surface heat flux into the building's envelope, Q_n, is expressed as:

$$Q_n = Q_{nsw} + Q_{n\ell w} + Q_c \qquad (1)$$

where Q_{nsw} = net shortwave radiation to surface
$Q_{n\ell w}$ = net longwave radiation to surface
Q_c = convective heat flux to surface,

a major reduction in the short wave radiation input to the surface is obtained by shading the building surfaces and the surfaces reflecting onto the building and also by lowering of building surface absorption and ground reflection. For the dry atmospheric conditions encountered at Phoenix, it was found that the building envelope has a large outward net longwave radiation which exceeds the total incoming absorbed radiation by four to five-fold. Since the net convective heat flux over a 24-hour period is small (of the order of 5% of Q_n) and in this case negative (heat loss), it becomes quite clear that a larger area of the building envelope is desirable for reducing interior air temperatures, if any added exterior surfaces are adequately shaded. This advantage of the court house configuration over a cubic house of same volume and height is seen in Table 2, which summarizes the major results of the present study.

Date, 21 of:	Building Height, L_z m	Results: / Variable Changed:	12 - Hour Day $(T_{ia})_{min}$, °C	12 - Hour Day $(T_{ia})_{max}$, °C	24 - Hour Day $(T_{ia})_{min}$, °C	24 - Hour Day $(T_{ia})_{max}$, °C
JUNE	3.35	—	23.8	27.0	22.1	25.3
	6.71	—	23.7	26.8	22.1	25.1
	12.71	—	23.6	26.6	22.0	24.9
		wall thickness t_w, m				
	6.71	= 0.23	23.0	28.6	21.2	26.4
	6.71	= 0.83	23.9	25.8	22.4	24.3
	6.71	exterior surface $\alpha = \varepsilon = 0.4$	24.2	27.6	22.7	26.1
	6.71	Cube House Geometry of same volume	23.7	27.0	22.2	25.4
DEC	3.35 6.71 12.81	—	16.7	17.3	16.7	17.7

Table 2: Major results of the present parametric study. Court house is oriented to north. The base configuration is defined in Table 1.

It can also be seen in Table 2 that the 12-hour (06:00-18:00) computation provides higher temperature predictions than the 24-hour computation, because it doesn't incorporate the night-cooling (thermal storage) effects. It may, however, be used as a conservative estimate if notable admission of warm air into the building during the day is expected.

The insolation and ambient temperature for the summer and winter days used in the computation, as well as some typical results, are shown in Figs. 5 and 6.

4. CONCLUSIONS

4.1 Orientation

The court house orientation has negligible effects on interior air temperature extrema, although a western orientation is slightly preferred in the case computed here.

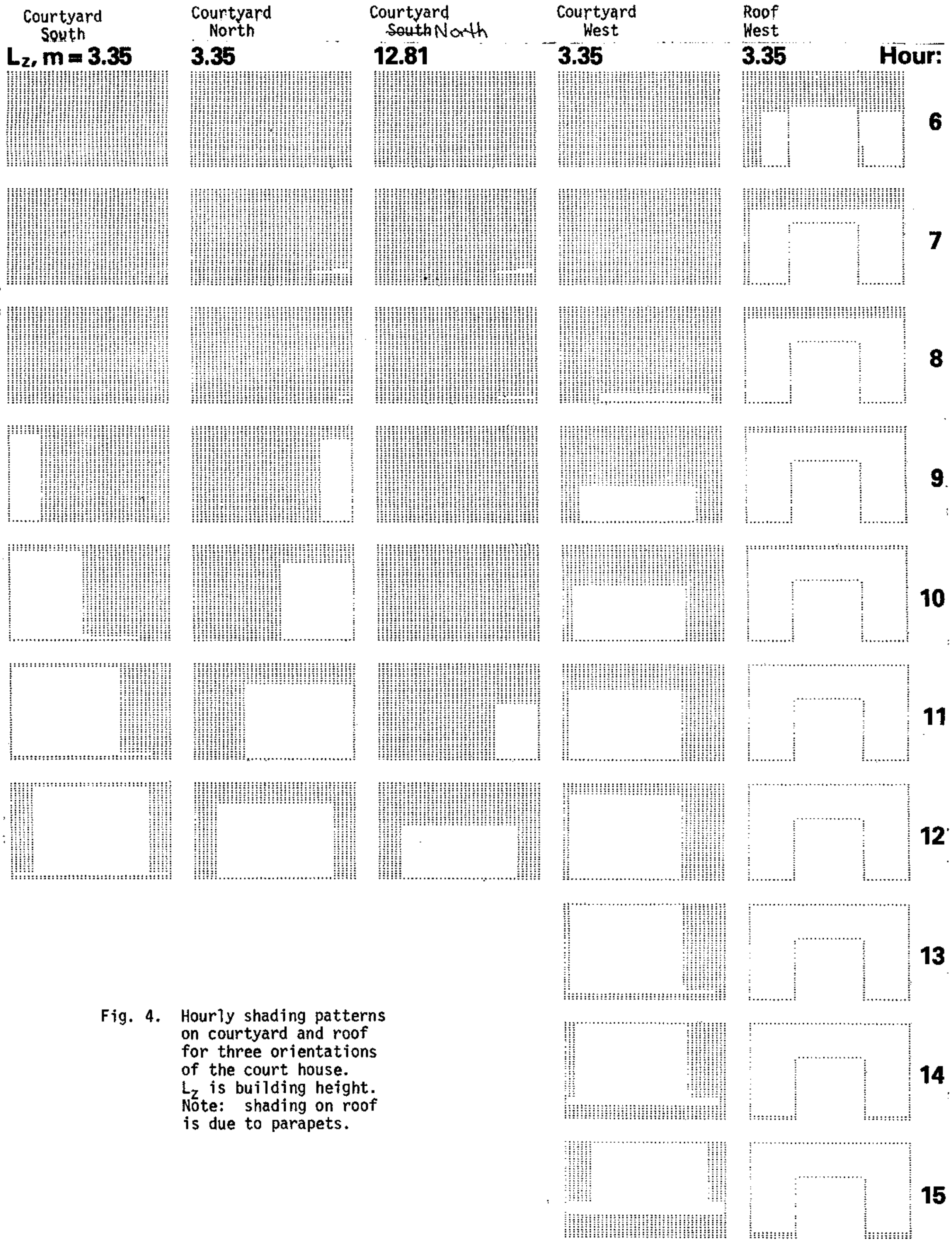

Fig. 4. Hourly shading patterns on courtyard and roof for three orientations of the court house. L_z is building height. Note: shading on roof is due to parapets.

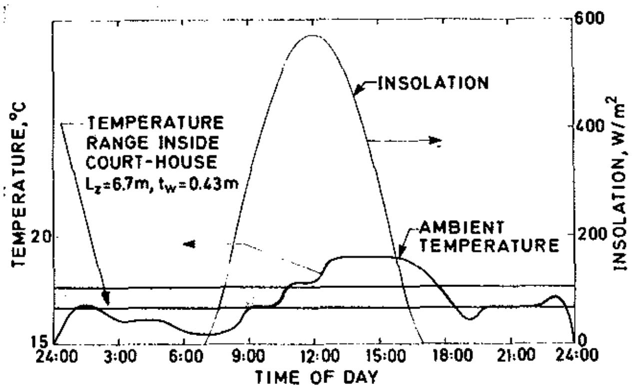

Fig. 5. Insolation and ambient temperature for 21 Dec ~~June~~ at Phoenix, AZ, with some computed typical interior air temperature bands.

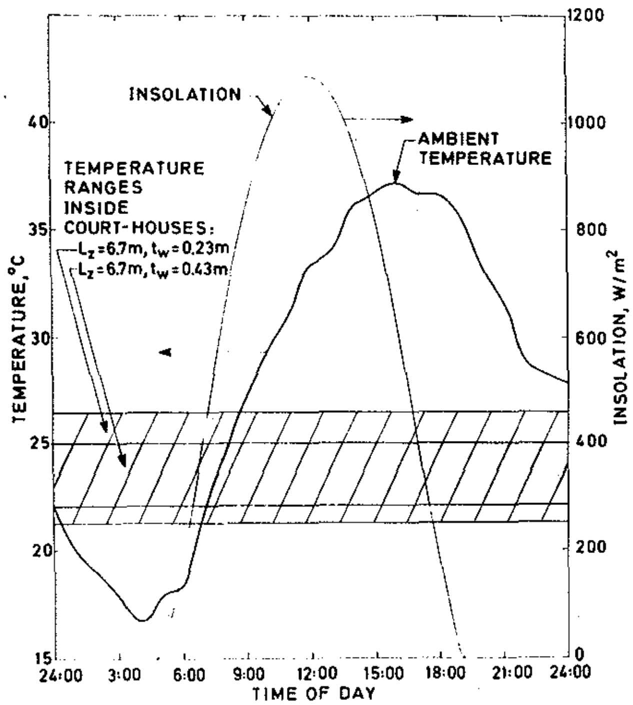

Fig. 6. Insolation and ambient temperature for 21 June ~~December~~ at Phoenix, AZ, with a computed typical interior air temperature band.

4.2 Building Height

For the same plan area, taller court houses maintain a lower interior temperature, partly because of larger extent of mutual shading, and partly because of the diminished influence of the hot roof due to its smaller area relative to that of the building walls.

4.3 Wall Thickness

As expected, temperatures inside the building are affected by wall thickness in a major way, creating an inreasingly even and comfortable temperature as wall thickness increases.

4.4 Longwave Emittance of Building Envelope

Since the major heat loss mechanism from the building in hot arid zones is longwave radiation, the longwave emittance of its exterior surface should be kept high to keep comfortable interior temperatures. A reduction of ε from 0.9 to 0.4 increases $(T_{ia})_{max}$ by 1°C.

4.5 Winter Operations

Neither building height nor orientation were found to have any practical affect on the court house's interior air temperature extrema for a winter day (21 December) at Phoenix, AZ. It is noteworthy in any case that building design in hot arid regions is oriented to summer conditions.

4.6 The Court House

The court house is thermally better adapted to hot arid climates than a house shaped as a cube which has the same volume.

4.7 Program TAD

The program is inexpensive (less than $5 per run) and easy to use for the thermal design of buildings by the comparison of their interior air temperature extrema for different configurations.

5. ACKNOWLEDGEMENT

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