Modeling the Temperature Effect of Orientations in Residential Buildings

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ABSTRACT:

Indoor thermal comfort in a building has been an important issue for the environmental sustainability. It is an accepted fact that their designs and planning consume a lot of energy in the modern architecture of 20th and 21st centuries. An appropriate orientation of a building can provide thermally comfortable indoor temperatures which otherwise can consume extra energy to condition these spaces through all the seasons. This experimental study investigates the potential effect of this solar passive design strategy on indoor temperatures and a simple model is presented for predicting indoor temperatures based upon the ambient temperatures.

Key Words: **Thermal Comfort, Indoor Temperatures, Orientation, House Plan.**

1. INTRODUCTION

Building sector in Pakistan is a major consumer of energy and particularly the residential sector [1]. Thermal comfort becomes an important quality that can make or break an environment quickly as the occupants live, work and play within the designed spaces. Therefore, the architects need to examine the local climate of an area because it is the leading factor in determining how heating and cooling requirements a house shall require [2]. Passive solar designing is the strategy for sustainable development, as it contributes to reducing energy consumption and environmental catastrophe [3] and fenestrations are a significant factor affecting thermal comfort in architecture [4]. About 20-30% of annual cooling load was found due to the windows in Florida homes [5] and windows were found to a critical component for the energy use of a residential building [6]. Many new housing developments have different plot sizes or blocks and their respective solar orientations which need to be carefully determined by the town planners to ensure thermal comfort at lesser energy consumption. Initial site planning integrating solar access for maximum number of plots/ blocks can have reduced cooling/heating requirements for the whole house plan configuration. The lot orientations with other passive design strategies can respond to the objective of thermal comfort at minimum energy consumption for any sustainable development. The south orientation with a tendency for west was found to be the optimum for cold and temperate climates [7]. Therefore, the designs of the buildings can control thermal comfort with the help of local climatic considerations at lesser energy consumption [8]. In Pakistan, the residential building sector consumes the about 52% of its energy resources as compared to other sectors [9-10]. In Pakistan, the traditional buildings show climatic consideration and

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control [11], but in later period of the modern architecture Reinforced Concrete construction (Fig. 1), consume more energy for their cooling and heating and due to improper solar exposure of the windows in their plan configuration. Pakistan is striving to sustain energy requirements and trying to absorb energy saving strategies and renewable energies. Practical information for passive control through building optimum orientation [12] should be available to the architects, developers and building users with respect to the local climatic context of Pakistan. This study is an attempt to model the temperature data collected and recorded for the prediction of indoor temperatures for establishing the practical information orientations in composite climate throughout the year.

The eight main orientations were taken for the investigation as Ph.D. research work on energy efficient house design [13]. The special instruments were selected for measuring indoor temperatures and the ambient outside temperature simultaneously. The long term temperature monitoring was done with the help of an Automated System to record the data of all test rooms simultaneously with remote access.

2. TEST ROOM MODULE

The test rooms for the experimental investigation were rotated at interval of 45^{o} as shown in Fig. 2. The architectural plan of the typical module of the test module is shown in Fig. 3. All the physical, thermal and architectural, properties of all rooms were kept identical except their orientations for this study. The architectural plan of the typical module or the test room is shown in Fig. 4. The (Walls 229mm) of the test rooms were made of bricks. The roof, 10mm was constructed with the prefabricated RCC (Reinforced Cement Concrete).

FIG. 1. CURRENT MODERN STYLE OF ARCHITECTURAL PRACTICE. PHOTOGRAPHS [SOURCE: AUTHOR(S) OF ONE OF THE NEW HOUSING DEVELOPMENTS IN LAHORE]

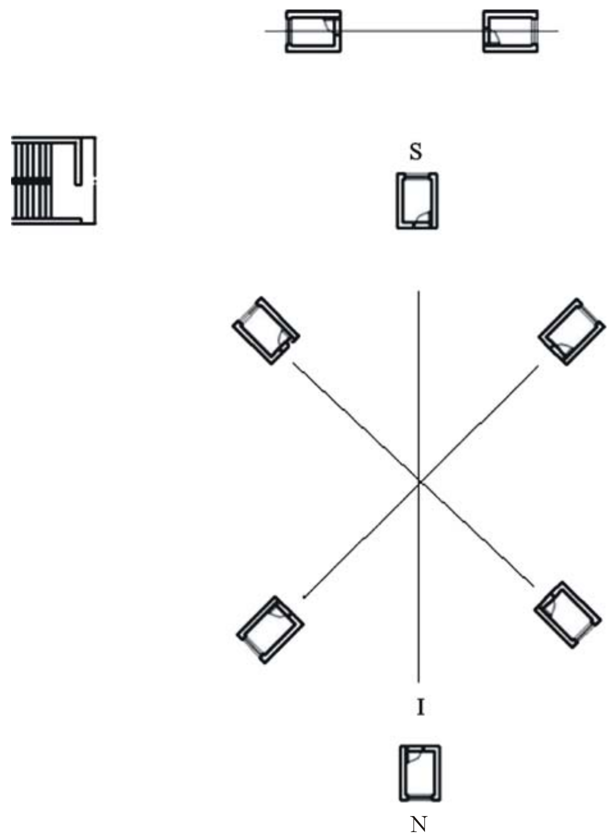

FIG. 2. ORIENTATIONS OF THE MODEL TEST ROOMS (DRAWING NOT TO SCALE)

FIG. 3. PHOTOGRAPH OF THE TEST MODULE

Each test room measures 1.60x2.30x2.00m, having a window area of 1.74m^2, facing towards the main orientations. A door (1.04m^2 area) was also provided to access and place the probes inside the rooms.

3. TEMPERATURE MONITORING SYSTEM

The temperature data of each test room was monitored, measured and recorded with the help of the Testo Saveris system, (Fig. 5) and the probes were installed in the center of each room as shown in the Fig. 6(a-b) to get the synchronized data.

The Saveris Base was connected to the Computer. The measurement data were obtained both in graphical and tabular output. The measured data could be viewed over several days, weeks and months with the help of integrated calendar definable with this equipment.

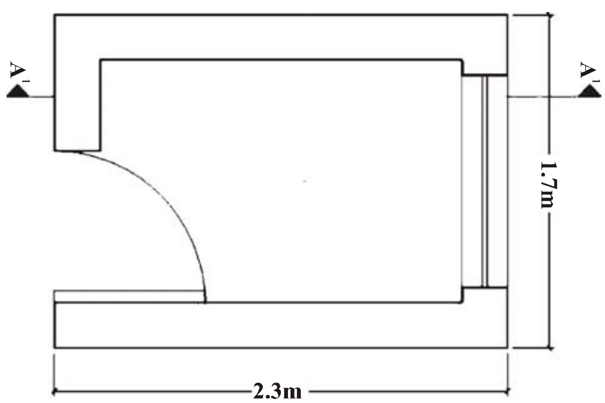

FIG. 4. ARCHITECTURAL PLAN OF EACH TEST MODULE

FIG. 5. TESTO SAVERIS SYSTEM

FIG. 6(a). PROBE INSTALLED

FIG. 6(b). PROBE FOR AMBIENT TEMPERATURE

The monitoring was designed to paint the real picture of the rooms' thermal performance. One hour interval was set to monitor the temperature variation after checking the variations at smaller time intervals. The temperature profiles for important seasonal dates were recorded for each orientation.

4. DATA MODELLING

It has already been described that the hourly temperatures for eight orientations have been monitored and recorded along with the ambient temperature. This data have been accomplished for the whole year. The temperature variations against time have been plotted in and can be verified from these plots that the hourly temperature in all the nine cases is a random variable. In the following sections an attempt has been made to correlate the ambient and directional temperatures individually for each month. The statistical relationships have been evolved so that design charts can be prepared from practical application.

4.1 Ambient Versus Test Rooms Temperatures

There is no doubt that room temperatures depend upon the ambient temperatures; however, this dependence is a complex phenomenon. The directional room temperatures have been correlated with the ambient temperatures in a simple model which is useful for design purposes. Basing upon the full month data, the relationship between ambient and room temperature for a given orientation has been proposed as:

$$T_\theta = A_\theta T_o + B_\theta \tag{1}$$

Where T_θ denotes the temperature for an orientation θ, T_o is ambient temperature for same orientation at any hour of day, A_θ and B_θ are two constants of the linear relationship. Table 1 shows the values of A_θ and B_θ along with R^2 values for the month of June, 2009.

The relational data given in Table 1 have been repeatedly established for all the months of a year, and finally for each month the values of A_θ and B_θ have been modeled as a function of direction θ. A polynomial relationship has been proposed as:

$$A_\theta = \alpha_o + \sum_{j=1}^{6} \alpha_j \theta^j \tag{2}$$

$$B_\theta = \beta_o + \sum_{j=1}^{6} \beta_j \theta^j \tag{3}$$

The model given above has been calibrated with the data of whole of the year 2010. The quality of fit and other statistical parameters are discussed in the following section.

4.3 Quality of Fit

The values of A_θ and B_θ of were taken for the month of June, 2009 from Table 1 and Equations was calibrated. The quality of fit may be verified from the Fig. 7.

A comparison of the Figs. 7-8 shows that the distribution of temperature data of the month of June from the two

TABLE 1. LINEAR RELATIONSHIP OF FOR THE MONTH OF JUNE, 2009

Direction	θ	A_θ	B_θ
West	0-360	0.65545	13.97727
North-West	45	0.63029	15.09622
North	90	0.64678	14.32080
North-East	135	0.68972	13.36029
East	180	0.68078	13.78630
South-East	225	0.68766	13.69109
South	270	0.67483	13.67730
South-West	315	0.63600	14.58202

years 2009 and 2010 is more or less identical. This is an encouraging sign and hence the design Equations (2-3) may be calibrated from the monthly data of any year and they will be applicable for the temperature data during that month of any other year in general.

Fig. 9 gives statistical fit of the directional data obtained from the month of July 2010. The major trend of this fit is similar to that of month of June, however, a notable differences may be pointed out; the variation of   is quite sharper in case of July 2010 as compared to the month of June 2010.

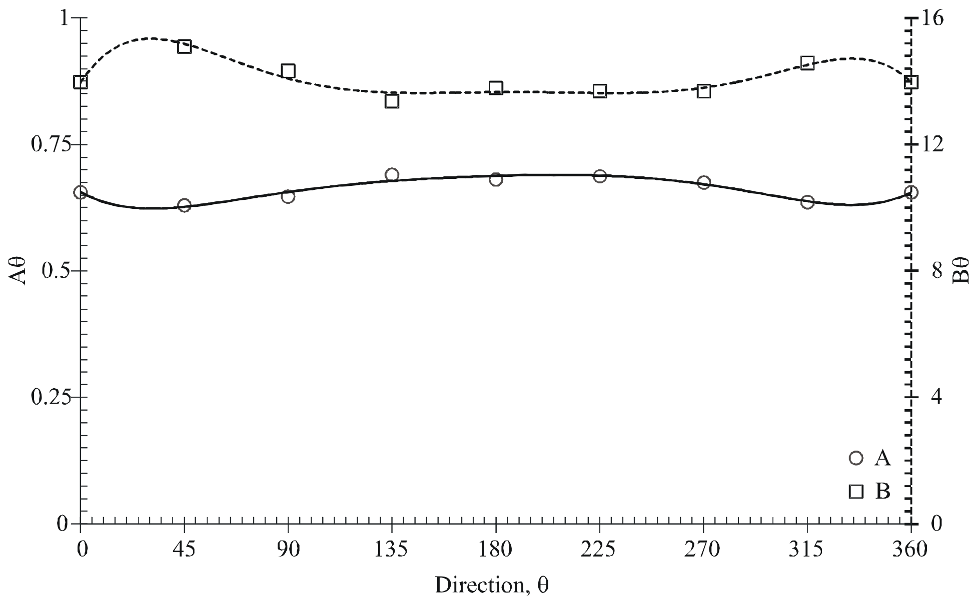

FIG. 7. THE FITTED RELATIONSHIP FOR THE DATA OF JUNE, 2009

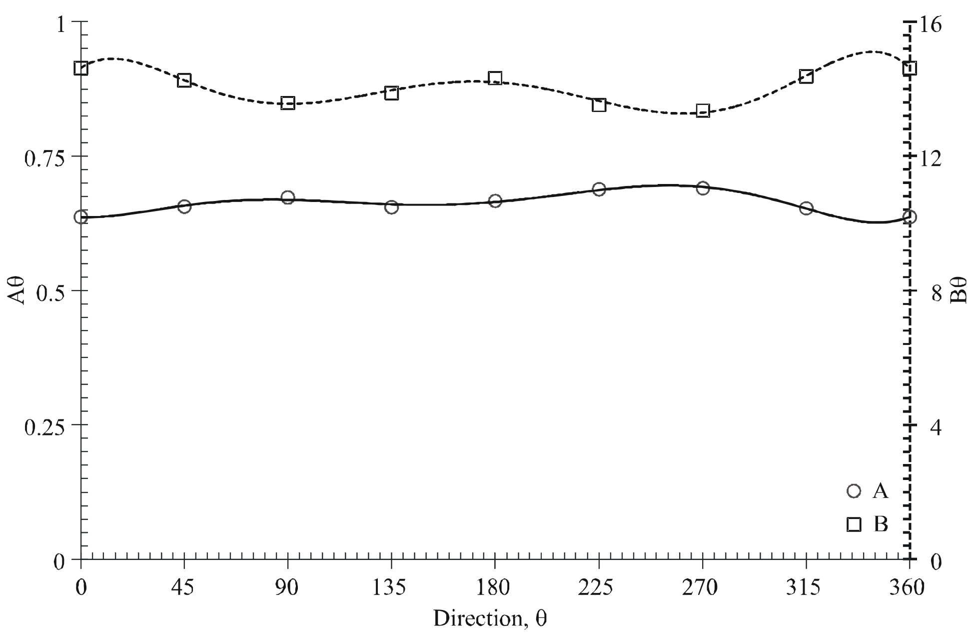

FIG. 8. THE FITTED RELATIONSHIP FOR THE DATA OF JUNE 2010

Another interesting fact is revealed by the comparison of Figs. 8-10, based upon the data of month of July where as Fig. 10 is obtained from the data of month of November. The variation of A_θ and B_θ is quite opposite in the two cases. For example, the curve of $B_\theta$is convex in negative direction for case of hot month of July and is positively convexed for the cool month of November. This feature is supportive of the fact that the orientations receive the sun rays if different ways during different months of the year.

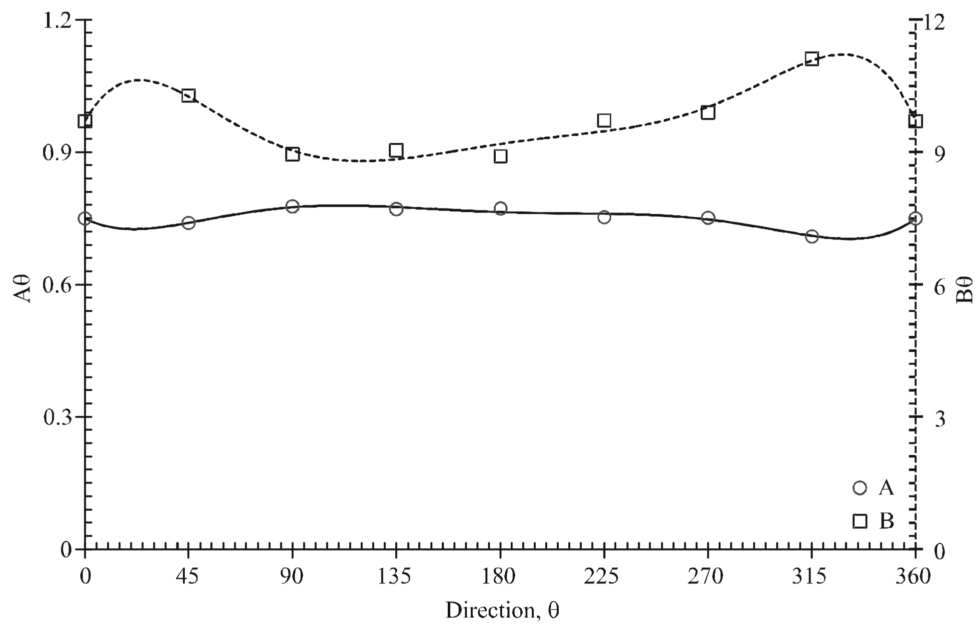

FIG. 9. THE FITTED RELATIONSHIP FOR THE DATA OF JULY 2010

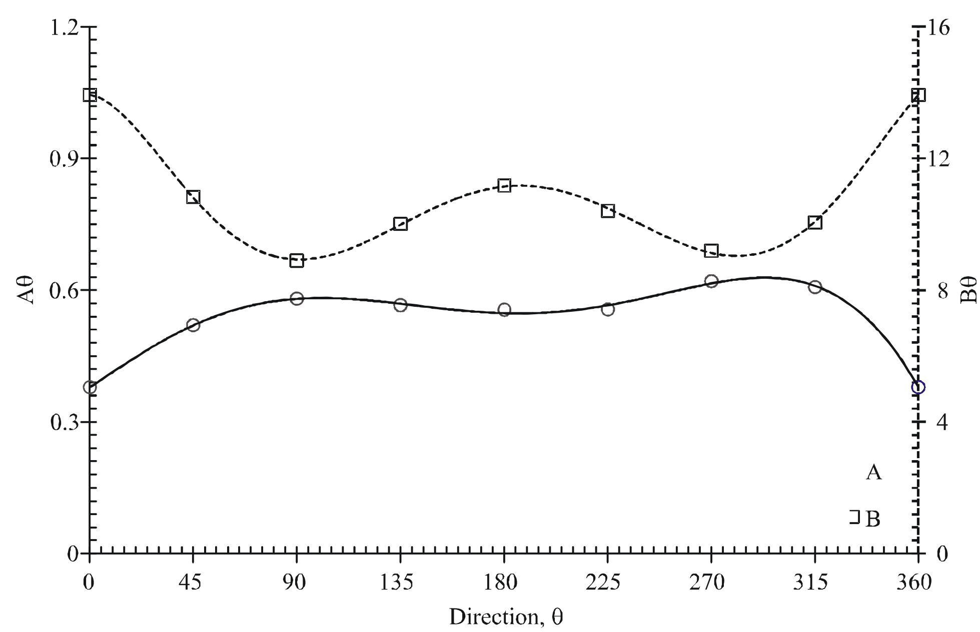

FIG. 10. THE FITTED RELATIONSHIP FOR THE DATA OF NOVEMBER 2010

It is very interesting to note the similarity between Fig. 11, former being for the month of November and latter is related to month of December. In other words, orientation data is varying in almost identical way during the coolest months.

4.4 Design Charts

The Equation (1) has been calibrated using the hourly temperature data for each month separately for each orientation θ. The west has been assigned 0° orientation, and the values are varied in clock wise direction. The value for orientation has been given in Table 1. Using the values of A_θ and B_θ month-wise, The Equations (2-3) have been calibrated. It may be noted that these results have been averaged for each month separately. If one has record of ambient temperature for a day of month or for a number of days of that month, using the appropriate set of coefficients α_j and β_j, the coefficients A_θ and B_θ of Equation (1) can be established for any orientation θ between 0-360°. Finally using this set of A_θ and B_θ with ambient temperature T_o, the room temperature T_θ for the given direction can be predicted.

5. CONCLUSIONS

(i) It has been established that adopting this passive strategy of orientation for residential buildings result in temperatures variations in different seasons at different angles of orientation(s).

(ii) This quantitative information of indoor temperatures as a function of ambient temperature can be employed in architectural planning for predicting heating and cooling for indoor thermal comfort.

(iii) Architects and Developers in Pakistan can achieve the national energy efficiency for temperature control in housing sector taking advantage of the optimized orientation for a sustainable future.

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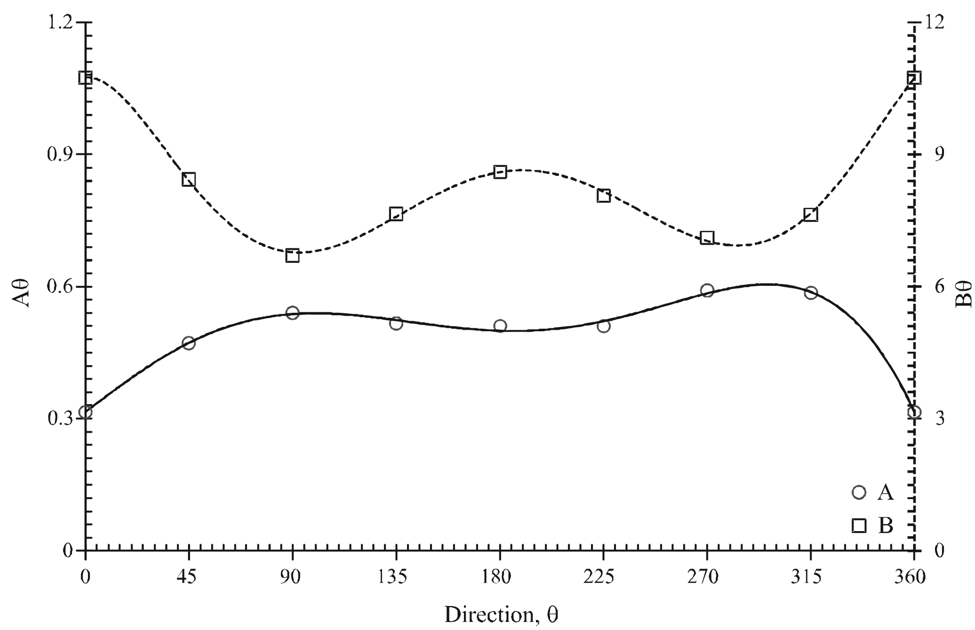

FIG. 11. THE FITTED RELATIONSHIP FOR THE DATA OF DECEMBER 2010

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