# A STUDY OF CO-RELATIONSHIP BETWEEN INTERAL TEMPERATURE OF BUILDINGS AND TREE SHADING IN HOT AND DRY CLIMATE

**Naeem Irfan,**
Associate Professor, Department of Architecture,
Mehran University of Engineering and Technology, Jamshoro.

**Adnan Zahoor,**
Divisional Forest Officer, Forest Department,
Government of Sindh.

**Nadeemullah Khan,**
Assistant Professor, Department of Architecture,
Mehran University of Engineering and Technology, Jamshoro.

## ABSTRACT

The study of tree shade on the internal temperature of a building in hot dry climate was examined using a computer – based model. Clear and hazy atmospheric conditions with solar radiation blocked (as if by trees) were considered for the study. Three shading conditions and ten shading regimes were chosen. It was found that tree shading has the most effective impact on the internal temperature of the building if the walls and roof are shaded.

Using a regression analysis a test of linearity was conducted to determine the relationship between the internal temperature of a building and an increase in tree shade. It was found that a negative linear relationship exists between the internal temperature and the amount of shade.

## 1. INTRODUCTION

Different studies have been carried out to determine the impact of trees on solar radiation. These studies were made through computer modeling techniques and field experiments. [1,2,3,4,5,6,7,8]. The studies are done in certain climatic regions under different conditions. A computer – based modeling technique was designed and used for an area of Lahore,(Pakistan) under clear and hazy atmospheric conditions

## 2. DISCUSSIONS

It was that the internal temperature of buildings in Lahore remains reduced constantly with solar altitude, but changes with clear and hazy atmospheric conditions. Reductions in internal temperature are found to be 2.4°F with increase in ten-percent shade when both roof and walls are shaded (Table - 01).

No particular tree species were chosen to study shading impacts on the inside temperature of buildings. This study is specifically designed to quantify the effects on internal temperature of buildings by irradiance reduction through tree shading.

The primary objectives are to:

1. Estimate the impacts on the internal temperature of the buildings increasing the percent tree shading, and

2. Determine if there is a linear relation between the amount of the shade on a surface and a buildings internal temperature

## 2.1 Advantage of Using Computer Models

For decades landscape designers and foresters have used microcomputers and energy analysis programs to design more energy efficient homes and commercial buildings.

Enormous problems and costs are associated with measuring microclimate because climatic variables constantly change over space and time. Given these difficulties and sparse funding, computer simulation techniques have been used in a number of studies.

Following are some of the advantages which led to the use of the computer model technique in the current project:

1. Computer simulation studies allow researchers to control variables that are often uncontrollable in the field.

2. Computer modeling is also cost effective because a large number of cases can be tested in a short period of time. Hence, Computer modeling holds promise as an economical method to enhance understanding of the interactions between climate, buildings and vegetation.

3. Computer models can provide quantitative data that urban foresters/landscape designers can use to plan and manage the urban forest/ landscape for enhanced energy conservation.

4. Models can also be used by designers to assist in the development of more energy efficient landscapes.

## 2.2 Limitations of Models

The scope of models written to simulate the impact of tree shade on inside temperature of buildings is limited mainly because microclimate itself is very complicated; it is difficult to simulate all the factors precisely. It is unrealistic to expect computer simulation result to match exactly the actual condition, but the results obtained through such models give ample evidence of the approximate impact of tree shade on the internal temperature of the buildings.

## 2.3 Development of Current Computer Model

The computer model developed for this study is based upon the following discussion and what follows is taken from Thayer, Thayer and Maeda, Givoni, Mazria, Harkness and Madan, Fathy, Barre, and Heisler [5,7,9,10,11,12,13,14].

Characteristics of internal temperatures of buildings are based on the external heat load. There are various ways in which the interior of a building gains this heat, and solar radiation is the principal source of it. Buildings derive significant portions of their heat energy from solar radiation. Solar radiation absorbed by a substance is converted into thermal energy; or heat. As heat is added to a solid material, its temperature rises. Therefore, temperature is the measure of the intensity of heat. This heat can be transmitted during the day to the building interior in a number of way.

The most important is by conduction. Solar energy reaches walls and the roof in the form of radiation, that is absorbed at the external surfaces and flows across the walls and the roof by conduction. Thermal conductivity is the property of a material which determines the heat flow in unit time by conduction through unit thickness of a unit area of the material, across a unit temperature radiant. Solar radiation absorbed by the molecule at the surface of a material accelerates heat movement. As the vibration movement of molecules in a material increases, the heat content of the material increases which is defined in terms of the movement of molecules; the more rapid this movement, the higher the temperature. Brick and concrete store and conduct heat much better than wood and are capable of transferring a large amount of heat from surfaces to interiors for storage.

Irradiance reduction from plant shade can have a substantial effect on the buildings' inside temperature. The shading can be used to prevent solar radiation from directly falling on the building. In this study, radiation reduction by tree shade was measured. Computer modeling techniques were explored to estimate the temperature reduction inside the buildings by reducing the input of solar irradinance. This technique consisted of tree shade and solar radiation, combined with a mathematical model at house surfaces.

The rate of conduction of heat depends on the thermal conductance of the building material used, the surface area receiving solar radiation, and the properties of the surface color. The extent to which plants reduce irradiance at the outside surfaces of buildings depends on:

1. The nature of the incoming solar radiation;
2. The amount of the surface area shaded, and
3. The shading coefficient of the plant.

### 2.4 Nature of Incoming Solar Radiation

Irradiance reduction by trees depends in part on the relative amounts of incoming direct and diffused radiation. A tree's leaves and branches absorb, transmit, and reflect both direct beam and diffused radiation. However, reduction of direct beam radiation is most important because it accounts for most radiation.

### 2.5 Surface Area Shaded

Simply stated, the more surface area that is shaded, the larger the irradiance reduction.

### 2.6 Shading Factor

It can be described as the irradiance reduction directly and is formally expressed as:

$$SF = \{ SA_s \} \ \{1\text{-}SC\}/SA_t$$

Where $SA_s$ is the surface area shaded and $SA_t$ is the total surface area and SC is the plant-shading coefficient. Engineering defines the shading coefficient of a shading object as the percentage of available solar radiation transmitted through the object.

This term can also be applied to describe the transmisivity of vegetation. Researchers have reported different shading coefficients for trees using different measurement techniques. In a leaf, coefficients range from 0.07 to 0.38. Hence the shading factor is a dimensionless number with values ranging from 0 (no shade) to 1 (complete shade).

## 3. METHODOLOGY

Hourly irradiance on the house surfaces for an average day on 15th June for the city of Lahore was calculated by adoption of the methods of Givoni, Harkeness and Madan, Fathy, Barre, Hartmann, Arya, Incropers, Karlekar, Jones and Ashrae [9, 11, 12, 13, 15, 16, 17, 18, 19, 20].

These methods were used in the calculation of total hourly radiation on horizontal roof and vertical wall surfaces, diffused radiation, reflected radiation from the building and transfer of heat through the walls and roof.

The input parameters used in the model are summarized in Table 1. Hourly outside temperature representing daytime hours were taken into consideration. This temperature represents temperature collected at the weather station situated in the city center which is 100 percent paved or developed. For computational purposes reduction in the inside temperature of the building in subtropical climate, for the month of June, by tree shading was modeled by making the following assumption:

1. Building is sited on flat homogeneous surface
2. Shade of the tree on the building is uniform
3. No adjacent houses
4. Housing orientation was assumed to be due east
5. No secondary effects of trees relating to energy conservation effects on air circulation patterns were assumed
6. No openings in the building
7. No ventilation
8. No inhabitant in the building

**TABLE-01**
**INPUT PARAMETERS USED IN THE STUDY**

| Input Parameters | Values |
|---|---|
| Latitude | 31° 35' North |
| Longitude | 74° 20' East |
| Atmospheric extinction coefficient | 21 percent |
| Solar radiation reaches the earth's outer atmosphere | 429.2 Btu/h/ft.sq. |
| Radiative heat transfer | 429.2 Btu/h/ft.sq.°F. |
| Diffused radiation for clear sky (hazy condition) | 0.35Ratio |
| Reflectivity of the concrete surface | 20 percent |
| Width of the wall of building | 6 inches |
| Absorption coefficient | 72 percent |
| Convective coefficient for outside | 0.756 Btu/h/ft² °F |
| Convective coefficient for inside | 0.42Btu/h/ft² °F |
| Thermal conductivity of solids | 0.5 Btu/h/ft² °F |
| Shading factors | 0-1 |
| Declination of sun in the month of June | 23.2 Degrees |

A computer program was developed in Visual Basic (Microsoft) computer language and Microsoft Excel spread sheet program to draw graphic relationships between the area shaded and the inside temperature of the building. Two approaches to simulate irradiance reduction were used in this study. In the first approach, a clear atmospheric condition was chosen, while in the second approach, hazy atmospheric conditions were selected. In both the approaches irradiance reduction by tree shading was measured by running computer simulations at three shading conditions (Table-02) and ten shading regimes, i.e. 0.1 to 1.

The house radiation climate model was run for shaded and unshaded buildings for clear and hazy atmospheric conditions. Internal temperature of the unshaded building measured by hourly solar radiance on the unshaded building was calculated. In this case the shading factor of the tree was kept zero.

Secondly, the internal temperature of the shaded building was measured at ten shading factors. Climatic factors calculated in the computer model to measure the impact of the tree shade on inside temperature of the building along with mathematical expressions is summarized in Table-03 and symbols used in these expressions are listed in Table-04.

Descriptive statistics were used to assess the presence and severity of departures from the assumptions of normality. To see the relationship between the percent tree cover and the internal temperature of the building a test of linearity was carried out by using SAS (Statistical Analysis System Institute Inc. 1990) [21] and Excel (Microsoft Excel) computer programs. Regression analysis was carried out at 0.05 level of statistical significance by using Proc Reg procedure. The regression model (Ott) [22] used in the analysis is as follows:

$$\Upsilon = \beta_0 = \beta_1 x + \text{Error}$$

Where as $\Upsilon_1$ is the internal temperature, $\beta_0$ is the intercept of the line, $\beta_1$ is the slope of the line and "X" is the tree shade. Regression analysis was applied on the daily averages of the internal temperature of the building generated by the model through computer simulations and "X$\Upsilon$ scatter graphs were drawn through Microsoft Excel.

**TABLE-02**
**SHADING CONDITIONS**

| | **Shading Conditions** |
|---|---|
| 1 | When both roof and walls were shaded (full shade) |
| 2 | When only walls were shaded (wall shaded) |
| 3 | When only roof was shaded (Roof shaded) |

## TABLE-03
## SUMMARY OF MATHEMATICAL EXPRESSIONS USED IN THE MODEL

Measurement of the intensity of direct radiation on the building.

IDN = I/Exp (E/sin (A)

Measurement of diffused radiation through the building.

IDF = k * IDN

Measurement of reflected radiation from the building

IRV = (IDN* r) /2

Measurement of heat transfer through the walls

Id = IDN*COS (A) *SF

Measurement of total Radiative heat transfer

II = Id+IDH IDF+IRV

Measurement of outside surface temperature of the roof

TSR = TA+ ((aa*II) /12) – 5

Measurement of outside surface temperature of walls

TSW = TA+ ((aa*II) /12)-2

Measurement of total outside surface temperature

TSI = (TSR + TSW /2

Measurement of convective heat transfer

q = - ((TA-TSI) / (1/CO))

Measurement of overall heat transfer into the building

TS2 = TSI –(q*(K/W)

Measurement of final inside temperature

T1 = TS2 – (Q*(1/CI)

## TABLE-04
## SYMBOLS USED IN THE DIFFERENT MATHEMATICAL EQUATIONS DURING THE DEVELOPMENT OF MODELS

**Symbol**

| | |
|---|---|
| SF | Shading Factor |
| A | Altitude of sun at each hour |
| E | Atmospheric extinction coefficient |
| I | Radiative heat transfer |
| k | Diffused radiation for clear sky condition |
| r | Reflectivity of the concrete surface |
| W | Width of the wall of building |
| aa | Absorption coefficient |
| CO | Convective heat coefficient for outside |
| CI | Convective heat coefficient for inside |

| | |
|---|---|
| K | Thermal conductivity of solids |
| TA | Outside ambient air temperature |
| IDN | Direct radiation |
| Id | Heat transfer through the wall |
| IDH | Heat transfer through the roof |
| IRV | Total reflectivity from the building |
| II | Total Radiative heat transfer into the building |
| TSR | Outside surface temperature of the roof |
| TSW | Outside temperature of the walls |
| TSI | Total outside surface temperature of the building |
| q | Rate of flow of heat into the building |
| TS2 | Conduction of heat through the walls and the roof |
| TI | Final inside temperature of the building |

## TABLE-05
## REDUCTION IN THE INSIDE TEMPERATURE WITH INCREASE IN PERCENT TREE COVER ON THE BUILDING

| Shading Regimes (Percent) | Atmospheric Conditions | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Clear Shading Conditions | | | | | | Hazy Shading Conditions | | | | | |
| | Full | | Wall | | Roof | | Full | | Wall | | Roof | |
| | AIT[1] | AR[2] | AIT | AR | AIT | AR | AIT | AR | AIT | AR | AIT | AR |
| 0 | 101.9 | | 101.9 | | 101.9 | | 97.5 | | 97.5 | | 97.5 | |
| 10 | 99.5 | 2.4 | 100.1 | 1.8 | 101.4 | 0.5 | 95.1 | 2.4 | 95.7 | 1.8 | 96.9 | 0.5 |
| 20 | 97.1 | 4.7 | 98.2 | 3.67 | 100.8 | 1.0 | 92.7 | 4.7 | 93.8 | 3.67 | 96.4 | 1.0 |
| 30 | 94.8 | 7.1 | 96.4 | 5.5 | 100.3 | 1.6 | 93.3 | 7.1 | 92.0 | 5.5 | 95.9 | 1.6 |
| 40 | 92.4 | 9.5 | 94.6 | 7.3 | 99.7 | 2.1 | 88.0 | 9.5 | 90.1 | 7.3 | 95.3 | 2.1 |
| 50 | 90.0 | 11.9 | 92.7 | 9.1 | 99.2 | 2.7 | 85.6 | 11.9 | 88.3 | 9.1 | 94.8 | 2.7 |
| 60 | 87.6 | 14.2 | 90.9 | 11.0 | 89.6 | 3.2 | 83.2 | 14.2 | 86.5 | 11.0 | 94.2 | 3.2 |
| 70 | 85.2 | 16.6 | 89.0 | 12.8 | 98.1 | 3.8 | 80.8 | 16.6 | 84.6 | 12.8 | 93.7 | 3.8 |
| 80 | 82.8 | 19.0 | 87.2 | 14.6 | 97.5 | 4.3 | 78.4 | 19.0 | 82.8 | 14.6 | 93.1 | 4.3 |
| 90 | 80.5 | 21.4 | 85.4 | 16.5 | 97.0 | 4.9 | 76.1 | 21.4 | 81.0 | 16.5 | 92.6 | 4.9 |
| 100 | 78.1 | 23.8 | 83.5 | 18.4 | 96.4 | 5.5 | 73.7 | 23.8 | 79.1 | 18.4 | 92.0 | 5.5 |

[1] AIT = Average Inside Temperature (°F) at different shading regimes.

[2] AR = Average Reduction in inside temperature of a building with increase in percent tree shade with reference to unshaded building (AR was calculated by estimating the slope of the line)

Distribution of raw inside temperature data generated by the computer model was first examined using the descriptive statistics in SAS to look for outliers and asymmetry. Very little evidence of asymmetry and outliers of the raw inside temperature data was found.

Therefore, the regression model seems appropriate for the analysis of test of linearity. The test of linearity shows that a negative linear relationship exists between the increase in percent tree cover on the building and the internal temperature (p value $\leq$ 0-.05). The slope of the line (Table-06) also shows negative linear relationship between percent tree cover on the building and the internal temperature in two atmospheric and three shading conditions. This means that increasing percent of tree cover on the buildings internal temperature decreases correspondingly in both clear and hazy atmospheric conditions (Graph-01& 02).

**TABLE-06**
**SLOPE OF THE LINE IN TWO ATMOSPHERIC AND THREE SHADING CONDITIONS**

| Atmospheric conditions | Shading conditions | Slope |
|---|---|---|
| Clear | Full | $\Upsilon = -0.24x + 101.9$ |
| | Wall | $\Upsilon = -0.18x + 101.9$ |
| | Roof | $\Upsilon = -0.5x + 101.9$ |
| Hazy | Full | $\Upsilon = -0.24x + 97.5$ |
| | Wall | $\Upsilon = -0.18x + 97.5$ |
| | Roof | $\Upsilon = -0.5x + 97.5$ |

Note: Slope is estimated through regression analysis.
X is percent shade.

## CONCLUSION

The results of the model developed for this study are very informative and several conclusions can be drawn from study. Higher internal temperature is predicted from a building without any shade. It was found that tree shading on the building reduced the substantial amount of internal temperature that in turn can reduce the cost of cooling in warm months. The reduction in internal temperature suggests that it is important to provide tree shade in the month of June. It was also found that tree shading has most impact on the internal temperature if walls and roof both are shaded.

This study also suggests that heat is mainly conducted through the walls. Shading the walls has more impact on the inside temperature of the building as compared to providing shade on the roof. This might be because walls have more surface area exposed to the sun. It was found that with the increase in tree shade on the building internal temperature of the building decreases correspondingly.

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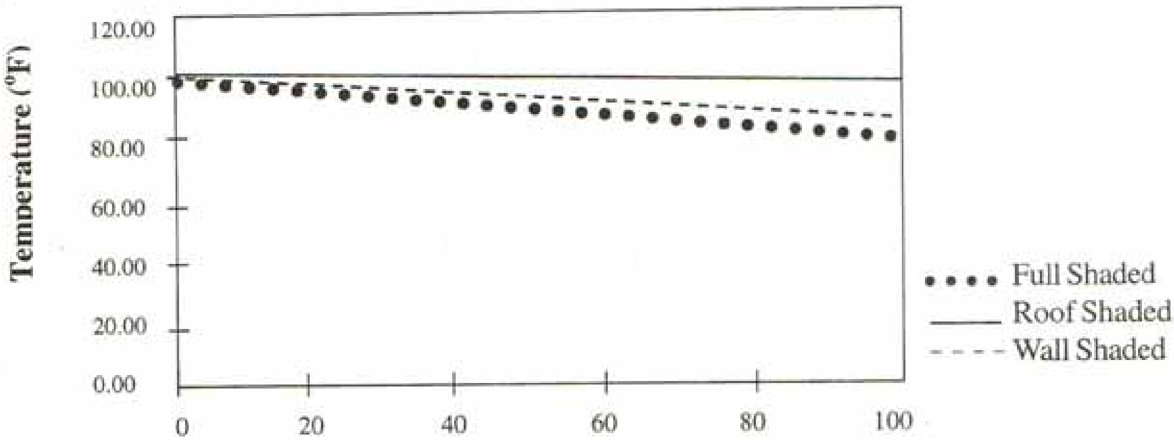
**GRAPH-01**

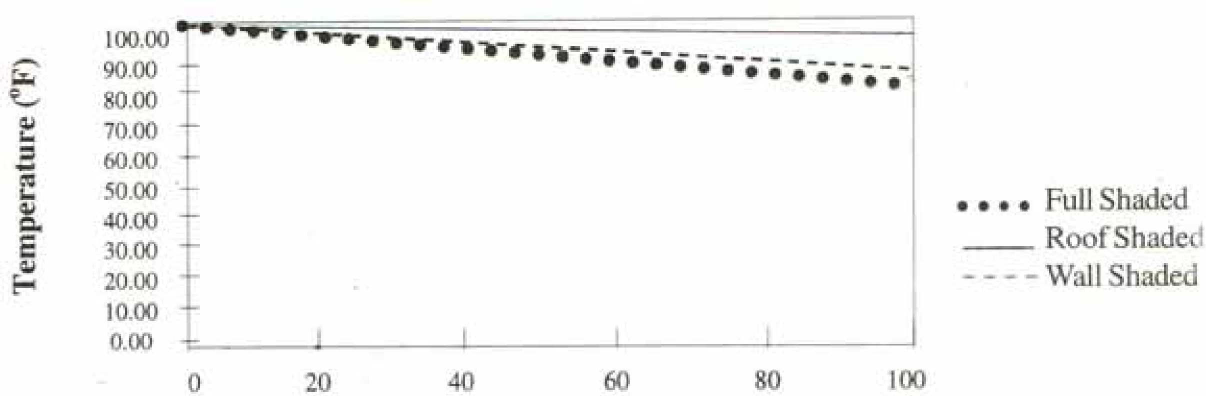
**SCATTER DIAGRAM SHOWING THE IMPACT OF INCREASE IN PERCENT TREE COVER ON THE INSIDE TEMPERATURE OF A BUILDING IN THREE SHADING CONDITIONS AND TEN SHADING REGIMES IN CLEAR ATMOSPHERIC CONDITION**




**Percent Tree Cover**

**GRAPH-02**

**SCATTER DIAGRAM SHOWING THE IMPACT OF INCREASE IN PERCENT TREE COVER ON THE INSIDE TEMPERATURE OF A BUILDING IN THREE SHADING CONDITIONS AND TEN SHADING REGIMES IN HAZY ATMOSPHERIC CONDITION**




**Percent Tree Cover**

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