IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 14, Issue 5 Ver. I (Sep. - Oct. 2017), PP 44-49
www.iosrjournals.org

Empirical Approach for Prediction of Indoor Air Temperature of a Building

B. M. Suman, P. K. Yadav
CSIR - Central Building Research Institute

Abstract: *In the present study a correlation between Building Index and indoor air temperature of a building has been developed. The Building Index is dependent on total peak heat load of a building. Analysis of fit linear polynomial for dataset indoor air temperature vs. Building Index has been made by MATLAB. Correlation factor for this empirical approach is 0.999 which shows the perfectness of the correlation. Prediction of indoor air temperature has been made simple by developing correlation equation through empirical approach.*

Keywords : *Building Index, Indoor air temperature, Peak heat load, Empirical approach, Thermal insulation*

Date of Submission: 29-08-2017 Date of acceptance: 08-09-2017

I. Introduction

Thermal insulation in building is a key factor to achieve thermal comfort of the occupants and reduction of heat losses, so diminishing the energy requirement for heating and cooling. The modes of heat transfer, i.e. conduction, radiation and convection, can be reduced through appropriate construction techniques and selection of insulation materials. The growing attention to energy savings in the building sector has led to more and more performing walls characterized by very low values of thermal transmittance. Thermal performance of an enclosure is dependent on the amount of heat flowing from outside to inside through building components and vice- versa. Building material is characterized by thermal conductivity to evaluate its ability to transfer heat by conduction through homogeneous layers of materials. Overall thermal transmittance value[1] of multilayer roof and wall section is used to determine heat gain factor of building section.

Thermal design of a building depends upon various parameters such as building materials and fabric specification, orientation, glass area, thermal insulation, shading, fenestration, ventilation rate and location of the building. Out of these parameters radiation exchange between various components of the building, relative humidity, heat flow through fabric and distribution of wind pattern contributes most influencing indoor thermal environment of a building. It is therefore obvious that thermal behavior of a building can be judged by the total peak heat flow resulting from individual components of heat flow.

Indoor air temperature is influenced by total peak heat load of a building which is determined by heat flow through roof and walls, distribution of wind pattern, radiation exchange between the various components of the building. An index known as Building Index (BI) [2,3] defined as the ratio of total heat gain into the room averaged over entire surface area of the room to the acceptable limit of heat gain 46.52 KW/m2 for achieving comfortable condition.

Three factors, namely climate of the place, thermal design and usage of building are very important to influence thermal performance of a building. It may be possible by thermal design alone to create indoor condition comfortable; therefore mechanical devices such as evaporative coolers or air-conditioners may be needed to pull down the thermal loads. In this regard building can be categorized into three types, the building (i) which do not utilize heating or cooling device and use electrical energy for indoor lighting and air motion, (ii) which uses heating and cooling device such as unit or split air conditioner, evaporative cooler, radiative or convective heaters and (iii) which uses AC plants to achieve indoor thermal comfort. Major of buildings in India falls either in first or second category. The paper presents some data on thermal performance of buildings under the influence of various design parameters. Measures to improve thermal performance of wall and roof have been studied in one of the author's earlier publications [4, 5]. The similar measures are suggested to improve thermal performance of wall and roof in this paper. The BI value is closely related with peak heat load through building fabrics which can be reduced by various methods, such as use of thermal insulation in building sections, suitable surface finish of external building surfaces. By reducing peak heat load, the BI- value is also reduced which leads to improve thermal performance of a building and reducing indoor air temperature as well.

II. Building Index

Total peak heat flow is the sum of heat flow through individual building sections. By considering the acceptable limit of heat gain for building 46.52 KW/m^2, the building index is simply computed by weighted average of heat gain factor through all the surfaces of the structure to the total surface area and numerically it can be determined by the following equation;

$$BI = \left[\frac{\sum_{i=1}^{n} A_i (HGF_i - 46.52)}{\sum_{i=1}^{n} A_i}\right] \quad (1)$$

Where, n is the number of building sections and $\sum A_i$ is the sum of all surface area of the structure.

The maximum limit of Building Index for different thermal comfort conditions and the corresponding indoor air temperature with a fan is given below in Table 1.

Table 1 Limit of BI corresponding to air temperature and comfort conditions

Building Index (BI) value	Indoor air temperature (o C)	Comfort condition with a fan
0-50	32	Comfortable
50-100	32-36	Slightly warm
100-150	36-40	Hot

Thermo-physical data [4] on performance of individual components of fabric for commonly used specifications are taken into consideration to determine building index. The uses pattern decides the non structural heat gain while developing building index, the effect of various design variables as exposure of wall and roof, thermal insulation, multi-storey construction, white wash, glass area, ventilation rates, water-spray on roof and night ventilation on building has been taken into consideration. It forms a suitable basis for comparing relative thermal performance of a building with respect to different design parameters. A higher BI value implies the need of mechanical device for cooling while a moderate value of BI suggests that a building can be made comfortable by suitable treatment such that white wash or use of thermal insulation.

III. Graphical method to determine Indoor air temperature

The building index, BI and indoor air temperature T_{ia} is closely related as T_{ia} is mostly dependent on total peak heat flow through all the surfaces of an enclosure. During development of BI, the data on about 50 cases covering various factors such as design parameters of roof and walls insulation, glass area, ventilation rates etc. were obtained for a typical summer day in hot- dry region of the country. As indoor air temperature quickly decides the indoor environmental condition, the building index is also related with comfort conditions. Different cases2 had been worked out to determine the indoor air temperature with the help of building index. The computations were made with different wall and roof specification, glass area, types of shading and surface finishes. Computed values of BI are correlated with indoor air temperatures. This correlated value is verified experimentally taking various cases and shown in fig 1.

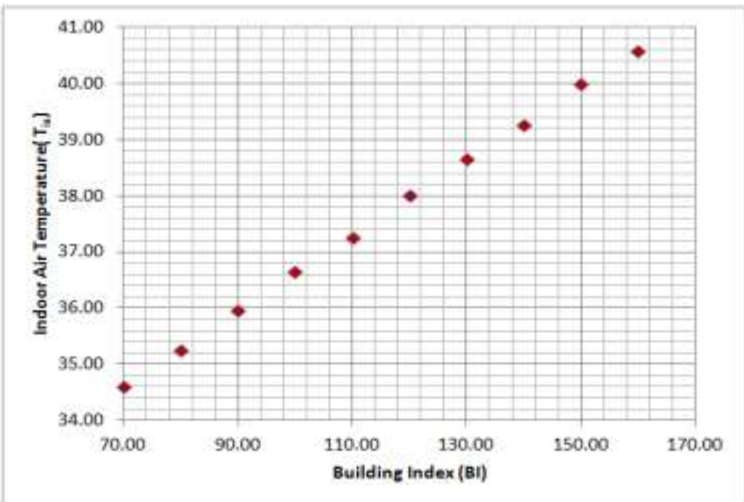

Figure 1 Indoor Air Temperature (Tia) for given Building Index (BI)

IV. Empirical approach to predict Indoor air temperature

The empirical relation has been established by developing empirical equation which correlates building index Value and indoor air temperature(T_{ia}). The equation correlating BI and T_{ia} has been explored using Linear Polynomial model shown in fig 2.

Linear Polynomial, $f(x) = p_1 * (x) + p_2$

The Coefficients (with 95% confidence bounds)

$$p_1 = 0.0672\ (0.06645, 0.06796) \text{ and } p_2 = 29.89\ (29.81, 29.97)$$

$$T_{ia} = 0.067 * (BI) + 29.85 \qquad (2)$$

This equation is found to be most suitable as the T_{ia} obtained by Graphical method as well as from empirical method is approximately same. The goodness of fit of our model is given above in table 2. The variations between the two methods are given in table 3. The minimum and maximum variations lies between the two methods are 0 and 0.11 ^oC respectively.

The software MATLAB has been applied to analyze the Building Index. Evaluation fit of the model at Building Index for predicting indoor air temperature has been carried out by assuming 95% prediction bound. The table 4 consist detail analysis of linear polynomial for dataset BI and T_{ia}. The analysis of fit linear polynomial for dataset indoor air temperature vs. Building Index has been shown in Figure 3.

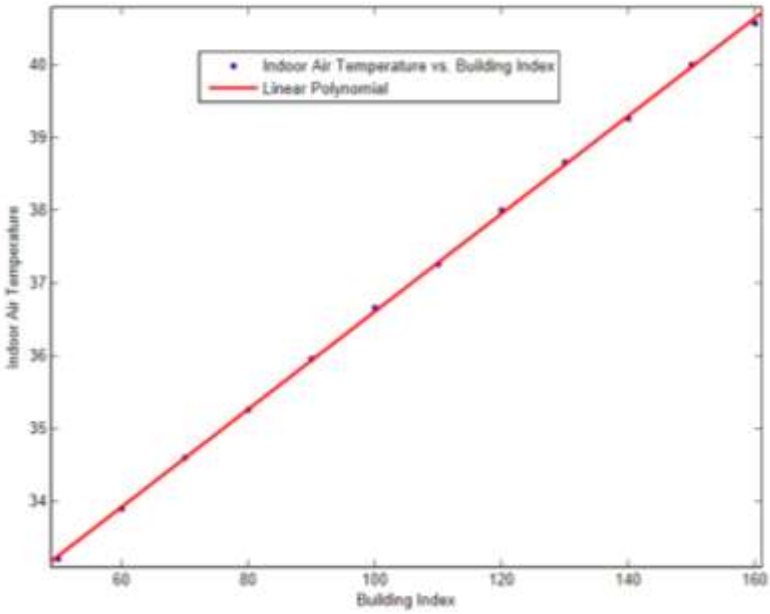

Figure 2. Linear Polynomial, Building Index $f(x) = p_1 * (x) + p_2$

Table 2 Goodness of fit of our model is

Sum of Squares Error (SSE)	0.0164	SEE is the sum of the squared differences between each observation and its group's mean. It can be used as a measure of variation within a cluster
R-squared	0.9997	R-squared will give some information about the goodness of fit of a model. In regression, the R-squared coefficient of determination is a statistical measure of how well the regression line approximates the real data points.

Table 3 Variation between the Indoor air temperatures determined through graphical method and by empirical approach

Building Index	T_{ia} obtained by Graphical method	T_{ia} obtained by Equation T_{ia} = 0.067*(BI) + 29.85 with $R^2 = 0.9997$	Variation
50.00	33.21	**33.20**	-0.01
60.00	33.90	**33.87**	-0.03
70.00	34.60	**34.54**	-0.06

80.00	35.26	**35.21**	-0.05
90.00	35.96	**35.88**	-0.08
100.00	36.66	**36.55**	-0.11
110.00	37.26	**37.22**	-0.04
120.00	38.00	**37.89**	-0.11
130.00	38.66	**38.56**	-0.10
140.00	39.26	**39.23**	-0.03
150.00	40.00	**39.90**	-0.10
160.00	40.57	**40.57**	0.00

Table 4 Analysis of fit "Linear Polynomial" for dataset "Indoor Air Temperature vs. Building Index

x_i	$Lower\ f(x_i)$	$f(x_i)$	$Upper\ f(x_i)$	$\frac{df(x_i)}{dx}$	$\int f(x_i)$
50.000	33.200	33.249	33.298	0.067	0.000
61.000	33.946	33.988	34.030	0.067	369.803
72.000	34.691	34.727	34.763	0.067	747.738
83.000	35.436	35.467	35.497	0.067	1133.800
94.000	36.178	36.206	36.233	0.067	1528.000
105.000	36.919	36.945	36.971	0.067	1930.330
116.000	37.657	37.684	37.712	0.067	2340.790
127.000	38.393	38.424	38.454	0.067	2759.380
138.000	39.127	39.163	39.199	0.067	3186.110
149.000	39.860	39.902	39.944	0.067	3620.960
160.000	40.592	40.641	40.690	0.067	4063.950

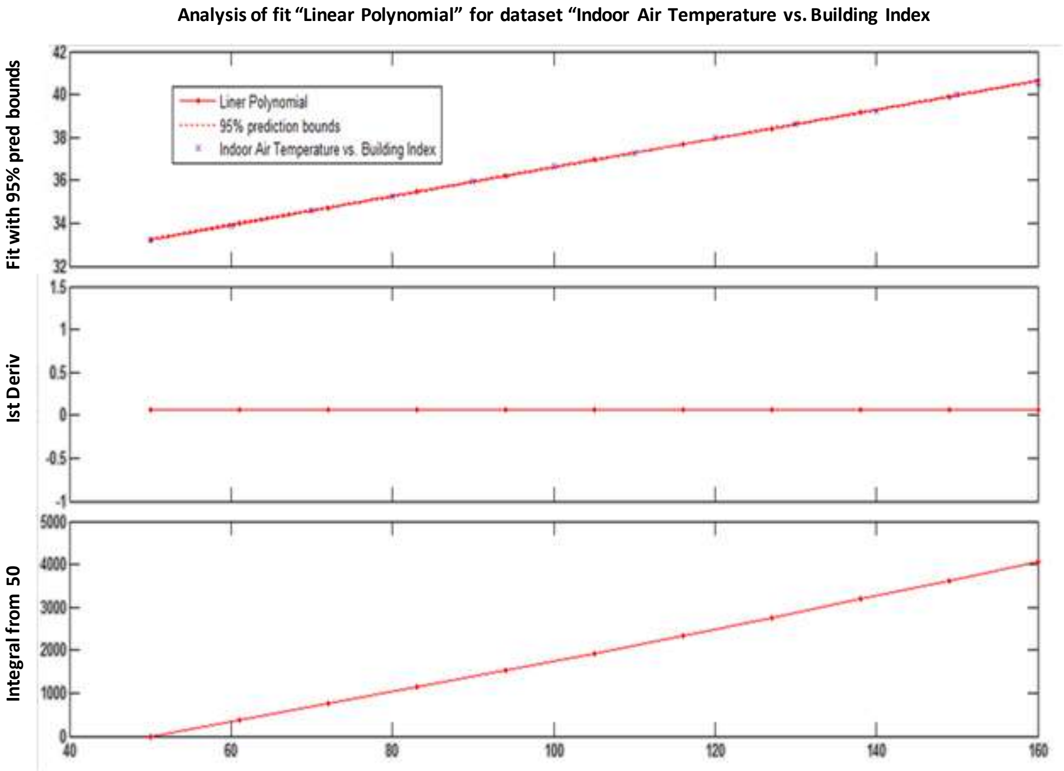

Figure 3 Analysis of fit linear polynomial for dataset between T_{ia} and BI

V. Indoor thermal comfort

The correlation between BI and Tia suggests that for reducing indoor air temperature of a building, its BI value may be reduced by treating the building sections. Heating/ cooling of a building is required to achieve indoor thermal comfort. It is important to assess the reduction in energy requirement using different types of treatment. The extent of reduction in energy requirements can be assessed with correlation between BI and corresponding comfort condition in building as given in Table 1. It can be explained with the following illustration.

Example:

Let a building with total surface area 100 m^2 has estimated its BI as 80. From table 1 corresponding BI value is 50. By reducing BI value from 80 to 50 the comfort indoor environment can be achieved. The total peak heat flow reduction can be determined as given below.

Q1 = (BI* Acceptable limit of heat gain)/ $\sum A_i$
= 80* 46.52/ 100
= 37.21 KW/m^2

Similarly for BI 50, the total peak heat flow can be determined as,

Q2 = (BI* Acceptable limit of heat gain)/ $\sum Ai$
= 50* 46.52/ 100
= 23.26 KW/m^2

The net reduction in total peak heat flow is found as,

13.95 KW/m^2.

The simple developed correlation equation is given by, $T_{ia} = 0.067BI + 29.85$, which can be utilized to determine reduction in total peak heat flow for reducing certain degree of indoor air temperature. This has been illustrated by the example given below.

Let us suppose that indoor air temperature, Tia of a non AC room is 40 ^oC. It is required to reduce indoor air temperature from 40 ^oC to 33 ^oC to achieve indoor thermal comfort. From the developed correlation equation, the values of BI for Tia, 40 ^oC and 33 ^oC will be 150 and 47 respectively. The total peak heat flow for BI values, 150 and 47 are determined as 69.78 $KW/m^2$and 21.89 KW/m^2respectively. This shows more than 68 percent decrease in total peak heat flow is required for reducing indoor air temperature from 40 ^oC to 33 ^oC. Peak heat flow depends mostly on over all thermal transmittance of building components.

VI. Discussion

A linear graph between T_{ia} and BI has been shown in fig.1. In this figure the corresponding indoor air temperature for 150 BI is 40^{o}C. The graphical method has been already verified in previous study [2] experimentally as well as theoretically for various cases. In one of the earlier study [6] the empirical approach has been utilized to estimate correlation between thermal and acoustical properties of mineral wool. The same empirical approach has been applied to predict indoor air temperature. The illustrations explained above suggest that total peak heat flow, BI value and indoor air temperature are related to each other. For any one of the three values, other two can be determined easily. Keeping indoor air temperature, T_{ia} of an enclosure from 40^{o}C and 33^{o}C, total peak heat flow is to be reduced by more than 68%. To reduce total peak heat flow of an enclosure, overall thermal transmittance of components of the enclosure, (roof, walls, window etc.) should be reduced in the same order. By using 2.5 cm good thermal insulating materials like expanded polystyrene, expanded poly ethylene, poly urethane foam etc in building components, overall thermal transmittance [5] of the components is reduced approximately by 68%. Lower indoor air temperature of a room is achievable as explained in this study with help of a Building Research Note published by CBRI Roorkee, especially for non AC buildings. The correlation factor R^2 is found to be 0.999 which shows there is a perfect correlation between BI and indoor air temperature, $T_{ia.}$

VII. Conclusion

Prediction of indoor air temperature has been made easier by developing empirical approach and equation of correlation between Building Index and indoor air temperature. The indoor air temperature, Tia can be reduced by just knowing the value of BI and treatment of building components with suitable thermal insulation or coatings. For example, to get Tia from 40^{o}C to 33^{o}C the corresponding BI will be reduced from 150 to 47. It is found for this reduction in Tia, total peak heat flow is to be reduced by more than 68% which can be achieved by treating building components with suitable thermal insulation.

Acknowledgements

Authors thank Director, Central Building Research Institute Roorkee for providing necessary facilities to conduct the study and permission to send the paper for publication.

References

[1] IS: 3792- 1978, Insulation guide for non- industrial buildings, *Bureau of Indian standard New Delhi,* (1978).

[2] Building Research Note 17, Thermal design of buildings- influence of design parameters, *Central Building Research Institute Roorkee publication* (1985) pp. 1- 4.

[3] Suman B M, Agarwal K N and Verma V V, Thermal performance of building components in tropical climate for thermal comfort in residential building, *1st Regional conference on EHH* held at Khartoum, Sudan, March 22- 26, 1995.

[4] Building Research Note 90, Data Bank on thermal insulation materials, *Central Building Research Institute Roorkee publication*, pp. 1- 8, 2011

[5] Suman B M and Saxena B K, Role of roof treatment in thermal design of building, *Architectural Science Review, Vol*.35 Dec, pp. 111-114, 1992

[6] Shrivatava R K, Dhabal R L, Suman B M, Saini A and Panchal P, An estimation of correlation on thermo-acoustic properties of Mineral wool, *JSIR, V*. 65, pp.232-236 , 2006

About the Authors

Dr B.M. Suman did his M.Sc degree in Mathematics (1989) and Ph.D Degree in Mathematics (1999). His Area of Research is in the field of Building Physics and application of Mathematical Modeling in Building Science. He has expertise in design of energy efficient building and energy simulation of building. Presently he is holding position of Principle Scientific Officer in CSIR-Central Building Research Institute. He has reviewed research papers on similar topic of the Institution of Engineers of Indian journal. Dr. Suman also holds the position as Associate Professor in the Discipline of Physical Sciences in Academy of Scientific & Innovative Research (AcSIR). Numbers of R&D projects have been successfully lead by him during his 35 years research career. More than seventy five research publications are to his credit He is principal member of BIS technical committees. Currently he is supervising one PhD student.

Dr. P. K. Yadav did his M.Sc degree in Mathematics (1983) and Ph.D Degree in Mathematics (1996). His Area of Research is in the field of application of Mathematical Modeling in Building Science & Technology, Distributed Computing System, Grid Computing, Network Security, and Fire Modeling are the areas of his research. Presently he is holding position of Principle Scientific Officer in CSIR-Central Building Research Institute. Dr. Yadav also holds the position as Associate Professor in the Discipline of Mathematical & Information Sciences in Academy of Scientific & Innovative Research (AcSIR). Dr Yadav has been awarded Shri M. S. Jain Beinel Memorial Award for Innovation Piling and other Construction Techniques by Indian Geo Technical Society and Golden Jubilee Director Award from CSIR-CBRI Roorkee. He has the life membership of many professional Societies and reviewed several research papers for the different reputed journals in the area of computer science and soft computing technique. He has contributed in many R & D projects in the field of Building Science Technology and more than one hundred research publications are to his credit. He has supervised 8 Ph.D students and four are pursuing Ph.D under him also evaluated many Ph.D thesis.

B. M. Suman. “Empirical Approach for Prediction of Indoor Air Temperature of a Building.” IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 14, no. 5, 2017, pp. 44–49.