iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 **Issue:** VI **Month of publication:** June 2019

DOI: http://doi.org/10.22214/ijraset.2019.6424

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue VI, June 2019- Available at www.ijraset.com

Building Passive Design & Housing Energy Efficiency - Upper North India

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Abstract: This study reviews to identify the relationships between real energy consumption data & building design data. A number of house were randomly selected as sample buildings for the study which introduces a method to use real energy consumption data to calculate the extra energy use related to winter indoor thermal conditions. Winter mean energy data & the extra energy usage related to winter indoor thermal conditions are used for investigating the relationships with design data related to the main architectural features, building elements & building materials. This study presents & identifies relationships between the increase in mean daily energy consumption data & trends of the building design data of the sample houses, & establishes the starting point & feasibility for further study to identify, in more detail, the quantitative relationships between building design data & energy consumption data for further developing passive design guides for building energy efficiency.
Keywords: Energy efficiency, Design guides, Housing design, passive energy design, Energy consumption.

I. INTRODUCTION

The first & best place to consider building energy efficiency is during the design of the building, nor when the building has been completed & is in operation. “It is not hyperbole to suggest that the better design of new buildings would result in a 40% -75% reduction in their energy consumption relative to 2000 levels, & that appropriate intervention in the existing stock would readily yield a 30% reduction” (Clarke, 2001). A number of recent studies have investigation & the upgrading of insulation levels to improve housing thermal performance or energy efficiency & to improve indoor health conditions. This study focuses on the impact of building design features on housing thermal performance & energy efficiency. On average of Upper North-India houses, space heating is the largest single end use (34%), followed by hot water (29%), appliances (08%), air-conditioning (10%) lighting (08%) & cooking (02%). Heating to raise low temperatures is the main use of household energy (63%), comprising space heating (34%) & hot water heating (29%), which are closely related to the winter indoor thermal condition of a house. Upper North-India does not normally need air conditioning or a ceiling fan for cooling during summer & only needs temporary heating during winter burning wood of electricity. In Upper North-India, the design of a building should focus more on its indoor thermal performance related to winter conditions for building energy efficiency.

The main focus of this paper is on winter energy consumption & the extra energy used in response to winter indoor thermal condition. To minimize the influence of differences in housing facilities & climates the study randomly selected more than 100 samples of houses in Upper North-India region which had been using electricity as their only energy resource for space heating, hot water, cooking, lighting, refrigeration & other appliances. The electricity consumption data for each sample house are for the same period of twelve months. Sample houses for this study include 50 houses with insulation materials in their roofs, walls and 50 houses without such insulation. The 50 sample houses with insulation include 15 one-story houses, 25 two storey houses, 5 three story houses & 5 four storey houses. The range of floor areas is 60-300 Sq.m. The range of occupancy per dwelling is 1-6 persons & mean number of occupants per dwelling is 4.5 persons. The range of floor areas per occupant is 22-150 sq.m. There are 25 houses with metal roofs (15 houses with brick walls and 10 houses with weatherboard & other walls), & 5 houses with wooden single roofs. There are 40 houses with internal garages & 10 houses without. The 50 sample houses without insulation include 30 one storey houses, 15 two storey houses and 5 three storey houses. The range of floor areas is 50-300 sq.m. The range of occupancy per dwelling is 175 sq.m. There are 25 houses with metal roofs (5 houses with brick walls & 20 houses with weatherboard & other walls) 25, houses with concrete tiles roofs (9 houses with brick walls & 16 houses with weatherboard & other walls) & 2 houses with wooden shingle roofs. There are 15 with internal garages & 25 houses without internal garages.

This study introduces a method to use real energy consumption data of a house of calculate the extra energy consumption resulted from the impact of winter indoor thermal conditions of the sample houses, which can be used to compare different designs of houses for energy efficiency & quantitatively indicate the difference of winter indoor thermal conditions between sample houses. The study uses differences between mean daily electricity usage in the winter months (October, November, December, January, and February) & other months of year to represent the extra energy usage related to winter indoor thermal conditions of the sample houses. The difference between mean daily electricity usage in the winter months & the other months can roughly represent the extra winter energy consumption, which mainly comprises space heating, extra energy for hot water heating & all appliances, which are impacted by the winter indoor thermal conditions of a house. The smaller difference between mean daily usage in winter months & the other months can roughly represent the better indoor space thermal conditions responded to the winter climate conditions.

This study uses the mean daily electricity usage per unit volume of house indoor space (kWh/m3/day) as the basic energy consumption unit, because the extra energy usage is mainly related to the indoor thermal conditions. The real mean daily electricity usages are mean daily electricity consumption on the monthly basis. All the new houses have insulation in their envelope according to the requirements of current building codes. The study mainly focuses on the relationships between the mean energy consumption data & design data of houses with such insulation to explore possible energy efficiency design guides for future housing developments.

This study also uses the mean winter energy consumption date to represent the winter thermal performance in the local climate conditions. Energy consumption data is to represent the winter thermal performance in the local climate conditions. Energy consumption data & building design data of the houses without insulation in there envelop are only used for comparison. This study takes account of the following design data related to the main architectural features, building elements & building materials of a building but excludes consideration of thermal passive controls or passive control systems such as passive solar heating, passive natural ventilation & evaporative cooling. The following parameters are affecting the analyses.

1) Energy Consumption Data & Insulation
2) Orientation.
3) Roofing material.
4) Internal garage
5) Ratio of building surface & building volume.
6) Ratio of total window area & total wall area.
7) Ratio of total window area & total floor area.
8) Ratio of North window area & North wall area.
9) Ratio of North, East, West & South wall & indoor space volume.
10) Ratio of North wall area & total wall area.
11) Ratio of total roof area & building volume.
12) Ratio of roof space volume & building volume.

II. DATA ANALYSIS

It is difficult to identify or isolate a clear relationship between a single design datum (such as the ratio of window to wall) & mean energy consumption data when other housing design data affect the building thermal performance simultaneously. This study will identify the relationships between the increase in mean daily energy consumption data & the trends of building design data variation, to explore design guides for energy-efficient housing design.

A. Energy consumption Data & Insulation

The mean daily electricity consumption data of the sample houses with & without insulation. Insulation within envelopes of sample houses is in accordance with local bye-laws of Upper North India. Annual & winter mean daily electricity usage of the sample houses without insulation is 38% & 45% more than for those with insulation. The difference between mean daily electricity usage during the winter months & other months for the sample houses without insulation is 85% greater than for those with insulation. Insulation is one of the most important design factors for housing energy efficiency. Differences between mean daily electricity usage per unit of indoor space during the winter months & other months for the sample house with & without insulation are, respective, 26% & 40% of winter mean daily electricity usage per unit if indoor space. Winter mean electricity usage per unit on indoor space for the sample houses & without insulation are, respectively, 32% & 35% of annual mean daily electricity usage per unit of indoor space. For improving Upper North India housing energy efficiency, improving the winter indoor thermal conditions through building passive design is crucial.

B. Orientation

Mean data shows that for a sample house with North orientation, differences between electricity consumption during the winter months & the other months are smaller than those for a sample house with different orientation. The mean data for houses with insulation are 0.0179kWh/m3/day for North orientation & 0.020kWhm3/day for different orientations. The mean data for houses without insulation are 0.0394kWh/m3/day for North orientation & 0.455kWh/m3/day for different orientations. For a house with North orientation, the greater the wall area exposed to the sun, the less energy is used for space heating.

C. Roofing Materials

For the houses without insulation, the difference between mean daily electricity usage during the winter months & the other months is less for houses with metal roofs (0.0426kWh/m3/day) than for houses with concrete tile roofs (0.035kWh/m3/day). As the R-value of concrete tile roofing materials is slightly higher than of metal roofing materials, without insulation in the roof space, the winter indoor thermal condition of a house with a concrete tile roof can slightly better than those of a house with a metal roof. For the houses with insulation, the difference between mean daily electricity usage during winter months & the other months is less for houses with metal roofs (0.0176kWh/m3/day) than for those houses with concrete tile roofs (0.021kWh/m3/day). If there are sufficient insulation materials on the upside of ceiling in the roof spaces, the difference in R-value between the concrete tile roofing & metal roofing is of negligible significance compared with R-value of the insulation materials in the roof spaces. For a house with sufficient insulation in its roof space, the type of roofing materials does not significantly affect the indoor space thermal conditions or energy efficiency.

D. Internal Garage

For the houses with insulation, the difference between mean daily electricity usage during winter months & other months is less for the houses internal garages (0.0195/kWh/m3/day) than for those houses without internal garages 90.0200kWh/m3/day). For the houses without insulation, the difference between mean daily electricity usage during winter months & the other months of is also less for houses with internal garages (0.0342kWh/m3/day) than for those houses without internal garages (0.040kWh/m3/day). An internal garages is considered part of the indoor space since it usually connects to habitable indoor spaces by internal indoor & external wall of the garage will usually have the same wall material & thermal insulation levels as other external walls. A warm car engine will add some heat to the indoor space. An internal garage can positively affect the energy efficiency of Upper North India house.

E. Ratio of Building Surface & Building Volume

The rations of building surface to building volume of sample houses with & without insulation are 0.4 to 0.9 & 0.4 to 0.8 respectively. An increase in differences between mean daily electricity usages during the winter months & the other months, winter mean daily electricity usage & annual mean daily electricity usage of the sample houses with & without insulation, is associated with an increasing trend in the ratios of building surface to volume. Housing passive design not only influences extra energy usage related to the winter & annual energy usage.

A house with a low ratio of building surface to volume has a small external surface area per unit of indoor space from which to lose heat to the outdoor, & use less energy for space heating, hot water & other appliances, which can be affected by indoor thermal conditions during the winter. When the difference between indoor & outdoor temperatures is same for houses with & without insulation, & the mean R-value of the envelope for a house with insulation is much higher than for a house without insulation, increasing the surface of both houses by the same amount results in a greater increase of heat loss for the house without insulation than for the house with insulation, during the winter.

F. Ratio Of Total Window Area & Total Wall Area

The ratio of total window area to total wall area of sample houses with & without insulation is 0.12 to 0.42 & 0.06 to 0.33 respectively. All the windows of all the sample houses for this study are single-glazed. An increase in differences between mean daily electricity usage during the winter months & the other months, & winter mean daily electricity usage of the sample houses with & without insulation, is associated with an increasing trend in the ratios of total window area to wall. Windows are weak areas of the building envelope for preventing heat loss during the winter. For Upper North India house with single-glazed windows, increasing the ratio of window to wall will negatively affect winter indoor thermal conditions, increasing the heat loss through the windows & the space heating energy consumption. The trend is for the sample houses with insulation to respond more strongly to the increase in differences of daily mean electricity usage than those without insulation. As a house with insulation has a bigger

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difference in R-value between the single-glazed windows to walls than a house without insulation, increasing the ratio of window to wall will more significantly & negatively affect indoor space thermal conditions of the house with insulation than on the one without.

G. Ratio Of Total Window Area & Total Floor Area

The ratios of total window areas to total floor areas for the sample houses with & without insulation are 0.10 to 0.37 & 0.10 to 0.46 respectively. An increase in differences between mean daily electricity usage during the winter months & the other months, & winter mean daily electricity usage of the sample houses with & without insulation is associated with an increasing trend in the ratios of total window floor areas. For Upper North India house with single-glazed windows, increasing the ratio of total window area to total floor area can increase the day lighting for indoor space, while not improving its indoor thermal conditions or energy efficiency.

H. Ratio Of North Window Area & North Wall Area

The ratios of North-facing window area to total North wall area of sample houses with & without insulation are 0.52 & 0.07 to 0.51 respectively. The placing of a large window on the North wall is a local housing design convention for daytime passive solar heating. For an old house without insulation, when the R-value of both the walls & the single-glazed windows are low, the more radiant solar heat that comes into the indoor space, the greater may be the positive impact on indoor thermal conditions & the reduction of energy consumption for space heating.

For sample houses without insulation, an increase in differences between mean daily electricity usage during the winter months & the other months, & winter mean daily electricity usage, is associated with a decreasing trend in the ratios of North-facing window area to North wall area. For sample houses with insulation, an increase in differences between mean daily electricity usage during the winter months & the other months, & within mean daily electricity usage is associated with an increasing trend in the ratios of North-facing window area to North wall area.

The occupants of a house with insulation may enjoy passive solar heating through large single-glazed windows during the short winter daytime, but during the longer winter night time, even when heater are on & the mean indoor air temperature is at a comfortable level, suffer unbalanced bodily heat loss to the cold indoor surfaces through radiation. With current building codes imposed to limitation on the ratio of North-facing window area on North walls to total North wall area, some local new houses have a large portion of North wall area covered by single-glazed windows simply because installing single-glazed windows is cheaper per square meter than building solid walls, building passive design for indoor thermal comfort must consider both daytime & night time indoor thermal comfort conditions to achieve housing energy efficiency.

For temperature climate conditions, building passive design for energy efficiency has to achieve or balance both summer & winter thermal conditions. Increase the single-glazed window area on North walls can negatively affect the energy efficiency of a house with good insulation. Large single-glazed window on North walls are simply a traditional local design convention based on older houses constructed without insulation materials. Now-a day's those single-glazed windows create wall area with low R-value in houses with good insulation but cold indoor surface areas. A house with good insulation loses a lot of heat though these "cold holes", which damages the entire housing passive design in term of energy efficiency & indoor thermal comfort. If the R-value of a window can match or come close to the insulation level of a wall-for example, a double-glazed window – a large window on the North wall can truly & positively affect the energy efficiency & the indoor thermal conditions of a local building. Design conventions need to combine with new building materials & new design concept for energy efficient building & thermal comfort.

I. Ratio Of Total North, East, West & South Wall & Indoor Space Volume

Upper North India is located in the Northern Hemisphere, walls on the South, East & West sides of a house may receive direct sun. The North side of the house should not receive the sun at all. An increase in the differences between mean daily electricity usage during the winter months & the other months, & winter mean daily electricity usage of the sample houses with insulation, is associated with a slightly decreasing trend in the ratios of South, East & West wall area to indoor space volume. Generally, increase the ratio of total South, East & West wall area to indoor space volume of the houses with sufficient insulation & appropriate windows, can positively affect their indoor thermal conditions & energy efficiency during the winter. An increase in the differences between mean daily electricity usage during the winter months & the other months, & winter mean daily electricity usage of the sample houses without insulation, is associated with increasing trend in the ratios of total South, East & West wall to indoor space volume.

Increasing the ratio of East, West & South wall area to indoor space volume also results in an increase in the ratio of building surface to volume. SAs the R-value of the envelope of a house without insulation is very low, the negative effect on winter indoor thermal conditions of increasing ratio of building surface to volume, can be stronger than the positive effect of increasing the ratio of total East, West & South wall area to indoor space volume, considering that solar radiation heat gain only occurs during the daytime. Housing passive design should consider the interactions & relationships of varies design factors, & balance their impacts on indoor thermal conditions & energy efficiency.

J. Ratio Of North Wall Area & Total Wall Area

Upper North India house with good orientation will usually have a high ratio of North ratio to total wall area. Good orientation should improve indoor thermal conditions & energy efficiency, but an increase in differences between mean daily electricity usage during the winter months & the other months is not associated with a decreasing trend in ratios of North wall area to total wall area for the sample houses with insulation. All windows in the sample houses with insulation are single-glazed, & the mean ratio of North-facing window area to North wall area (0,30) of these houses is higher than the ratios of East-facing (0.24) & West-facing windows (0.22). Therefore increasing the ratio of North wall area to total wall area also significantly increases the North-facing single-glazed window area with a very low R-value compared with the insulated walls. The negative effect of increasing the ratio of North-facing window area to north wall area may be stronger than the positive effect of increasing the ratio of North-wall area & total wall area for the houses with insulation & single-glazed windows. The energy efficiency of a house with sufficient insulation & good orientation can be negative impacted by single-glazed windows with low R –value. An increase in differences between mean daily electricity usage of the sample houses without insulation during winter months & the other months in associated with a slightly decreasing trend in ratios of North wall area to total wall area. A house without insulation shows a much smaller difference between the R-value of the single glazed window & the wall, than a house with insulation. For the house without insulation, increasing the ratio of North wall area to total wall area could positively affect its energy efficiency.

K. Ratio Of Total Roof Area & Building Volume

For sample houses with & without insulation differences between mean daily electricity usage during winter months & the other months, & winter mean electricity usage during winter months & the other months, & winter mean electricity consumption, increased along with increases in the ratio of roof area (excluding eaves) to building volume. As Upper North India house loses about 40% of its heat through the ceiling & roof during the winter, an increase in the ratio of roof area to building volume will increase the total heat loss & the space heating energy consumption of a house.

L. Ratio Of Roof Space Volume & Building Volume

For example houses with & without insulation an increase in difference between mean daily electricity usage during winter months & the other months, & winter mean electricity consumption, is associated decreases in the ratio of roof space volume to the building volume. The trend in the sample houses without insulation is to respond more strongly & clearly to the increase in differences between mean daily electricity usage during the winter months & the other months. For houses without insulation, air with low conductivity in a large floor space can increase the R-value of the roof when limited air movement occurs in the roof space. For houses with insulation, the increase the R-value caused by increasing roof space volume is very small compared with R-value of the insulation materials on the upside of the ceiling in the roof spaces. Increasing the roof volume does not significantly affect the indoor thermal conditions & Energy efficiency of a house with sufficient insulation in the roof space.

III.CONCLUSION

The study introduced a method to use actual mean daily electricity usage of the sample houses in Upper North India to calculate their extra energy consumptions related to the winter indoor thermal conditions for comparing housing designs focusing on the winter thermal performance.

This method could also be applied to other building types & other climate conditions. For a climate with a hot summer & comfortable winter such as a hot-humid climate, the difference between mean daily electricity usage in the summer months & the other months of the year can be used to evaluate & compare different building designs focusing on the summer thermal performance. For a climate with both stressful summer & winter, the difference between mean daily electricity usage in the summer months or the winter months & the other months excluding the winter months or the summer months of the year can be used to evaluate & compare different building designs focusing on both the summer & the winter thermal performances.

Successful building passive design for energy efficiency should take different design factors related to architectural features, building materials into consideration as a whole. Ignoring one design factor could damage the energy efficiency of an entire building. For example, the single-glazed window can negatively affect the energy efficiency of Upper North India house despite it having sufficient insulation. Successful building passive design for energy efficiency of should combine local design traditions with new building materials & new design concepts for building energy efficiency. Some local design traditions however, based on old building design concept & materials, should be reviewed in the light of new design concept & materials. For large windows on North wall of the houses can negatively affect indoor thermal comfort & building energy efficiency of the house despite sufficient insulation.

Some design conventions are beneficial for the thermal conditions of a building only during the daytime (or a particular season). Successful building passive design for energy efficiency should consider both daytime & nighttime (& both winter & summer). For house energy efficiency design, the building code should require window to have a compatible R-value the insulation envelope of the house, or limit the ratio of single-glazed windows to walls.

Although different design data related to the main architectural features, building elements & building materials can affect the extra energy consumption related to winter indoor thermal conditions differently & simultaneously, this study shows that the relationship between the increase in extra energy consumptions & the trend of the design datum's variation (such as the ratio of window to wall variation can still be identified. This preliminary study forms the basis of, & confirms the feasibility for, a further study using a much larger sample, which can identify the quantitative relationships between the increase in extra energy consumption & the trend of the variation in a design datum. With a sufficient number of sample buildings, the gradient of the trend line of the design datum's variation could be used to evaluate the strength of impact on extra energy consumption, the estimate the increase or decrease of extra energy consumption when a design datum is changed within a range & the other design data also impact the extra energy consumption differently & simultaneously. If the building code indicates the relationship between the design datum & the extra energy consumption, architects & designers could with their design pencils make a significant difference to building energy efficiency & take responsibility for it.

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