PARAMETRIC ANALYSIS USING DYNAMIC ENERGY SIMULATION TOOLS 
TO EVALUATE THE PERFORMANCE OF BUILDING ENVELOPE IN THE RESIDENTIAL BUILDINGS OF COMPOSITE CLIMATIC REGION OF INDIA

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ABSTRACT

Results of monitoring of electricity consumption in typical multi-storey residential flats in the composite climate region of India, have shown that 30-60% of the annual electricity consumption is used for space conditioning, mainly cooling of bedrooms and living room. Most of the cooling load in the residential buildings originates from solar heat gains and heat transmission through the envelope (through windows, walls, and roof). Thus, special attention is needed to reduce solar heat gains and heat transmission through improved building envelope. Until recently, the passive heat gains were overlooked. This study aims at demonstrating the importance of passive features on reducing the gross thermal cooling energy demand. This paper discusses the results of the thermal performance (performed using TRNSYS 17 software) and daylighting analysis (performed using ReluxPro Professional software) of typical bedroom and living room cases. The paper discusses the impact of various building envelope features on the gross thermal cooling energy through parametric simulation analysis. The analysis includes parametric analysis of window to wall ratio, external wall to floor-area ratio, wall insulation, external finish of the wall, window design, and shading systems, on the thermal performance and daylighting of the building, and provides recommendations from an energy-efficiency perspective. The potential of gross thermal cooling energy reduction is of 23-56% depending of the package of measures. The tool used was the Parametric Generator developed under VBA in the Excel environment.

This work was carried out under the Indo-Swiss Building Energy Efficiency Project (BEEP) and resulted in the development of guidelines for the design of energy efficient residential buildings for composite climatic regions of India (BEE, 2014).

INTRODUCTION

The rapid urbanization in India has led to an unprecedented increase of the built area in the recent years as some recent estimation of the total construct built-up area could increase by almost 5 times as compared to today’s situation.

In the frame of the Indo-Swiss Building Energy Efficiency Project (BEEP), the results of a study including more than 1100 dwellings in New Delhi and Chennai area (Kanagaraj Ganesan et al. 2014) show that the energy consumption for comfort cooling is the largest single component of the electricity consumption ranging from 33 to 65% of the total. This paper discusses the results of the gross cooling thermal performance (performed using TRNSYS 17 software) and daylighting analysis (performed using ReluxPro Professional software) of typical bedroom and living room cases studying in detail the interactions between insulation, solar protection and natural ventilation.

SIMULATION AND/OR EXPERIMENT

The simulation model has been developed to provide the basis of the Design Guidelines of Energy-efficient Multi-storey residential buildings for composite, hot, and dry climate (BEE, 2014). The Delhi climate has been used for the study and the guidelines. Until now, residential building are not under any energy related code. The only energy code which now enforced in some of the Indian States (notification to date in Rajasthan, Odisha, Uttrakhand, Punjab, Karnataka, Andhra Pradesh and UT of Puducherry) is the Energy Conservation Building Code (ECBC, BEE) which is applicable for new commercial buildings having a connected load of 100 kW or more. In residential dwellings, the internal loads are lower than in commercial buildings, and generally, the cooling set point is often fixed at a higher value (in the range of 24-26 °C). The temperature is, during part of the day, also sometime free-floating.

The guidelines address energy efficiency of different parts of a residential flat as well as services, renewable energy. In this paper, only the methodology, the simulation and results for the gross thermal cooling energy demand of bedrooms are presented. More than 300 parametric variations have been performed with the Parametric Generator giving input files to TRNSYS 17, launching the runs and retrieving results from the simulation cases for the analysis and development of the Guidelines.

The main objective of the parametric studies was to highlight the importance of the contribution of each
energy efficiency measure (orientation, insulation, window to floor area ratio, static/movable solar shading, and natural ventilation) and highlight the most efficient combinations reducing gross thermal cooling energy demand. The cooling set point was also one of the parameters considered. Heating has not been considered in the study. The study including more than 1100 dwellings has shown that heating energy demand was marginal under Delhi climate (Kanagaraj Ganesan et al. 2014).

In order to be able to perform a large number of simulations, a “Parametric Generator”, which was developed earlier, was further developed for this purpose. The “Parametric Generator” developed in the MS Excel environment with Visual Basic Application allowing to change the chosen parameters in the TRNSYS input files (.dck) as well as in the building input files (.bui). The TRNSYS batch runs are launched from the application. The results of each simulation are then re-imported in the “Parametric Generator” (Jaboyedoff, 2014). Comparative graphs of results are generated automatically. They include a numerical and a graphical description of each case simulated (Figure 11: Comparison of relative gross thermal cooling demand for the energy efficiency package I, II and III versus the base case versus ... generated automatically with the Parametric Generator for the).

The TRNSYS developers have provided a parametric tool named TRNSED (Wisconsin, Solar Energy Laboratory, 2010). This parametric application allows generating parametric studies and input masks for non-advanced users of TRNSYS. TRNSED is very friendly user. The objective developing the Parametric Generator was to be able to perform parametric studies rapidly using any simulation model base consisting of a building input file (.BUI) one related TRNSYS input file (.DCK) changing not only constants but also expressions. The tool allows replacing practically any chain of character having a mix of numerical and alphanumerical data. The tool has been developed in VBA language for Excel.

**RESULTS OF THE PARAMETRIC STUDY**

For the guidelines readers, in order to make the strategies more understandable, the gross cooling thermal energy demand has been referred to the base case as being 100%.

The simulations have been performed with a 15 minutes timestep over the entire year with the ISHRAE files for New Delhi climate, considering that it was representative of the hot composite climate. New guidelines for other climates of India (for example hot and humid climate) are presently under development.

**Base case for a bedroom**

The base case for a typical bedroom was defined based on the analysis of typical floor plans of real projects (see Table 1: some inputs parameters for the simulation of the base case for bedrooms). The model developed for bedrooms (3 x 3.7 x 3 m) is for intermediate floor with ceiling and floor modelled as adiabatic. The orientation of the external walls is south-west.

It consists of a bedroom having two external walls (most common typology) with 230 mm uninsulated brick wall. The glazing is a single 6 mm clear glass. There is a 500 mm horizontal static overhang at the lintel level. The intermediate floor is made of 150 mm thick RCC slab. The window to floor area ratio is equal to 27% or the window to wall ratio is equal to 15%. The external wall-to-floor-area ratio is equal to 181%.

The plan and section (see Figure 7: Schematic of base case model for bedroom developed in TRNSYS) shows the dimensions and the main heat gains distribution. The cooling temperature set point is constant and equal to 26 °C (more variations were performed for the guidelines 24-26-28 °C). Air conditioning equipment is not simulated. Only gross thermal cooling energy is accounted for, focusing on envelope design impact. Energy performance of air conditioning systems are equally important, but not part of this study.
It is important to notice that the heat gains through the window represents more than 50% of the total heat gains on a typical hot day.

Table 1: some inputs parameters for the simulation of the base case for bedrooms (taken from BEE, 2014)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall</td>
<td></td>
</tr>
<tr>
<td>External wall: 230 mm brick wall</td>
<td>U-value: 2.0 W/m²K, surface absorptivity: 0.05</td>
</tr>
<tr>
<td>Internal wall: 110 mm brick wall</td>
<td>U-value: 3.2 W/m²K, adiabatic</td>
</tr>
<tr>
<td>Glazing</td>
<td></td>
</tr>
<tr>
<td>6 mm single clear glass</td>
<td>U-value: 6.1 W/m²K</td>
</tr>
<tr>
<td>SHGC: 0.85</td>
<td></td>
</tr>
<tr>
<td>VLT: 0.9</td>
<td></td>
</tr>
<tr>
<td>Shading on the window</td>
<td>500 mm horizontal overhang at lintel level</td>
</tr>
<tr>
<td>Intermediate floor</td>
<td>U-value: 3.0 W/m²K</td>
</tr>
<tr>
<td>150 mm RC slab</td>
<td>Adiabatic</td>
</tr>
<tr>
<td>Window-to-floor area ratio</td>
<td>27%</td>
</tr>
<tr>
<td>External wall-to-floor area ratio</td>
<td>18%</td>
</tr>
<tr>
<td>Window-to-wall area ratio</td>
<td>15%</td>
</tr>
<tr>
<td>Occupancy load and schedule</td>
<td>Schedule for weekdays: 2 persons, (21:00-07:00 hours) Schedule for weekends: 2 persons, (22:00-07:00 hours) and (14:00-17:00 hours)</td>
</tr>
<tr>
<td>Set-point</td>
<td>26 °C</td>
</tr>
<tr>
<td>Location</td>
<td>Delhi</td>
</tr>
</tbody>
</table>

Package measure n°1
The package I consists of solutions that are commercially available and are already being implemented in some of the multi-storey residential buildings.
The main parameters changed are:
- Use of light colors on external walls (absorptivity <= 0.4)
- Window shades with extended overhangs (0.5 m on both sides by 0.5 m)
- Insulated walls (U-value: 0.7 W/m²K)
- Optimised natural ventilation (50% of effective window area opened when the outside temperature is cooled than the indoor temperature)
The schematic view is shown on Figure 8: Schematic of Package I measures. Application of these measures can reduce the thermal cooling demand by 23% depending on the orientation.

Package measure n°2
The package II consist of the Package I measures with in addition
- external movable window shutters
The schematic view is shown on Figure 9: Schematic of Package II measures with external operable shutter. This second package allows to reduce the thermal cooling demand by 46% when compared to the base case.
By adding simple external windows movable shutters, the package II allows to increase further the saving by 23%.

Package measure n°3
The package III consists of the the Package II measures with in addition:
- insulated walls (U-value: 0.5 W/m²K)
- Double glazed windows (U-Value: 2.8 W/m²K)
- Improved building tightness (reduction to about 0.35 ACH)
The third package allows reducing the gross thermal cooling demand by 56% when compared to the base case.

Daylight analysis
The daylight analysis was performed using the Radiance software and the Relux pro software interface, for a typical bedroom of 3 by 3.7 meters. For the daylight analysis, the base case has a window to wall ratio of 15% and an overhang of 0.5 m depth over the window, as shown in the model and plan below. It was performed with the aim of highlighting the potential problems with high rise buildings which are narrow spaced.

Other parameters are as follows: Ceiling height 3.2 meters, Single glazing with Visual Light Transmittance of 80%, sill at 0.9 m, reflectivity of walls 50%, ceiling 70%, floor 20%, outside wall finish 20%
The first important highlight of the study is that a window to wall ratio of 10% was found to be sufficient to ensure sufficient daylight in the bedroom. In this
case, the average daylight factor along the middle of the bedroom is 1.1%, which is above the threshold of 0.9% as defined in other studies (Based on the German DIN Norm 5034), (see Figure 3: daylight factor in the bedroom for the base case with a window to wall ratio of 10%). Therefore, daylighting was further studied to identify the situations where the short distance between buildings had a negative influence and look for alternative solutions for improvement.

Figure 3: daylight factor in the bedroom for the base case with a window to wall ratio of 10% and an overhang of 0.5 m depth

The second important finding of the study is that daylight becomes very scarce for the lower floors in the case of multi-storey residential complexes, particularly if the towers are more than 12 floors high and if the buildings are situated less than 10 meters apart.

The study performed for a similar bedroom on the second floor of a 12-floor tower, situated 6 meters apart from the neighbouring block (value which is below the typical bylaws minimum value) has shown that daylight becomes very scarce. The average daylight factor along the middle of the bedroom is below 0.4% in this case (see Figure 4: daylight factor at second floor level for very narrow spaced buildings).

Figure 4: daylight factor at second floor level for very narrow spaced buildings (10 m space between buildings)

The first option is to have light coloured finishes, no overhang, and to increase the window to wall ratio. By combining 30% window to wall ratio, light coloured finishes and no overhang, the daylight situation becomes satisfactory (see Figure 5: daylight factor on the second floor with light finishes, no overhang with narrow space between buildings). In this case, the average daylight factor along the middle of the room is 0.9%.

Figure 5: daylight factor on the second floor with light finishes, no overhang with narrow space between buildings and an increased window to wall ratio to 30%

The second option is to increase the distance between the buildings to 18 meters or more. With a distance of 18 meters between the tower blocks, combined with light finishes, the daylight becomes satisfactory. The average daylight factor along the middle of the room is 0.9% (see Figure 6: daylight factors in a bedroom on second floor level of tower block with light finishes, no overhang and increased distance between buildings to 18 meters).
DISCUSSION AND RESULT ANALYSIS

The TRNSYS 17 simulation model was developed using the experience of appropriate use of simulation model of the authors gained with more than 25 years of experience with TRNSYS 14, 15, 16, 17 releases with natural ventilation and cooling applied to real designs and compared with real performances after construction and obtaining good matching. In addition, detailed comparisons with real measurement in India have been also performed satisfactorily on few projects. The main results of the strategies toward energy efficient residential buildings are shown on Figure 11: Comparison of relative gross thermal cooling demand for the energy efficiency package I, II and III versus the base case versus (generated automatically with the Parametric Generator for the . The package I allows reduction of about 23% of the gross thermal cooling energy demand against the base case. The package II allows a reduction of about 46% against the base case. The package III allows a reduction of 56% against the base case.

Result analysis

The package I represents energy efficiency measures which are taken today by some builders in the market. The proposed package II differs from package I by the addition of external movable shutters. This simple measure (which one can see in most of Southern regions in Europe) allows almost doubling the relative energy saving when compared to the package I. The package II measures are the most efficient in term of cost/efficiency. Thanks to the efficient dynamic solar protection, the insulation is also more efficient in the building system than in the package I.

CONCLUSION

This parametric study performed with the “Parametric Generator” (Jaboyedoff, 2014) allowed demonstrating in a systematic manner the potential of gross thermal cooling energy demand reduction for various orientations (only one orientation shown in this paper), window to floor area ratios, glazing quality, and insulation thickness. In addition, external solar movable protections (external movable shutters) are shown to be the most efficient and simple way to improve the energy efficiency and comfort conditions in composite, hot, and dry climates in residential buildings.

Many efforts will be needed to achieve energy performance in the residential sector. This study does highlight the need of the large-scale introduction of external movable shutters along with insulation. These passive measures on the envelope can bring up to 50% of reduction of the gross thermal cooling energy demand. The experience accumulated with external movable shading devices in continental Europe over the last three decades has demonstrated practically the importance of external movable shutters/blinds in reducing cooling loads. It is now a main stream practice.

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Wisconsin, Solar Energy Laboratory, 2010, TRNSYS 17.0
Figure 7: Schematic of base case model for bedroom developed in TRNSYS (figures taken from BEE, 2014)

Figure 8: Schematic of Package I measures (about 23% reduction in gross thermal cooling energy)
Figure 9: Schematic of Package II measures with external operable shutter (about 46% reduction in gross thermal cooling energy)

Figure 10: Schematic of package III (about 56% reduction in thermal cooling energy)
Figure 11: Comparison of relative gross thermal cooling demand for the energy efficiency package I, II and III versus the base case versus (generated automatically with the Parametric Generator for the Design Guidelines for Energy-Efficient Multi-Storey Residential Buildings)