A Case Study of Energy Demand in Housing Units

Contributors:
Niket Kumar¹, Former Graduate Student
Dr. Sudhir Misra¹, Professor
Dr. Naveen Tiwari², Associate Professor

¹ Department of Civil Engineering, Indian Institute of Technology Kanpur
² Department of Chemical Engineering, Indian Institute of Technology Kanpur

July 21st, 2017
Outline

- Motivation
- Introduction
  - Whole Building Approach
  - Thermal Energy Performance Evaluation
  - Calibrating Building Energy Simulation Model (BESM)
- Objective
- Simulation Tool
- Methodology
- Results and Discussion
- Conclusions and Scope of Future Work
Motivation

- With Current Policies IEA predicts the global energy demand of buildings to grow by 30% in 2035 in comparison to 2010
- Complying buildings with ECBC guidelines can lead to 40 - 60% less energy usage than conventional buildings
Whole Building Approach


Source: CLEAR (Comfort and Low Energy ARchitecture)
Introduction: Thermal Energy Evaluation

Actual house

3D Modelling

Input Parameters: Weather, House orientation, Envelope properties, Indoor air properties as per actual conditions

Simulation Outputs

Tune input parameters

Input parameters values are established for given period and condition

Compare

Collected Actual Output Data

Building Energy Efficiency and thermal comfort outputs

Thermal Energy Performance Evaluation

Simulation
Calibrating Building Energy Model

Model
- 3D geometry information
- Other input information (building orientation, indoor and outdoor conditions)

Data Collection
- Indoor air temperature and surface temperature
- Heating / Cooling Energy Demand

Calibration
- Vary input parameters iteratively to model
- Arrive at max match with the simulation outputs (Calibrated)
Objective

- Thermal energy performance evaluation of a prefabricated housing unit in New Delhi
- Calibration of whole building energy model using measured indoor temperature and hourly heating energy demand
- Parametric study by varying parameters relating to weather, material, indoor and surrounding environment of unit
- Aimed at achieving optimized energy consumption and thermal comfort for the unit
Simulation Tool: TRNSYS 17

- Input parameters
- Building description
- Simulation outputs

3D Modelling of building in Google Sketchup

Type – 56 Multizone building
Methodology of this study

- Identification and calibration of measuring instruments
- Case study of LGS unit with modelling and simulation
- Validation of building energy model (BEM) using collected data
- Parametric Study of Calibrated Model
Instrumentation

- Thermocouple Wires
- Laptop (Terminal)
- Data Acquisition System
- Digital Temperature Measurement
Instrumentation

- Digital electricity meter
- Attached thermocouple on north facing wall
- Attached thermocouple on inside wall surface
- Attached HF sensor on inside wall surface
Case Study

- Location
- Weather
- Geometry and surrounding description
- Sketch-up Model Implementation
- Envelope Parameters
- Simulation conditions
Location

Location of Light Gauge Steel Building in Housing Park (Shown in red circle)
Weather

A suspended thermocouple sensor employed at outside of room for ambient temperature measurement

Details of measured ambient temperature connection to type 56 multi-zone building
Geometry

Perspective view of top floor of LGS housing unit under study

Plan of LGS housing unit top floor under study
Sketchup Model Implementation

3D Model of LGS unit developed in Google Sketch-up to generate *.idf file
Envelope and Surrounding Parameters

Surrounding Description around housing unit

Cross section of wall made of multilayered structure

Cross section of roof made of multilayered structure
Calibration by Tuning

Initial Model (IM)

Do sensitivity analysis to find parameters to be tuned

Find the value of parameters with maximum match to simulation results

Iterate to find the best possible value of input parameters

Calibrated Model (CM)
Terminology:
1. Thermal Transmittance (U-Value): Measure of how effective a material is an insulator. Lower U-value means better heat insulator.
2. Albedo: Proportion of the incident light or radiation reflected by a surface
3. Internal Gain: The sensible and latent heat emitted within an internal space
4. Set Temperature: The desired indoor air temperature (achieved through heating or cooling system)
Results and Discussion

- Calibration by tuning
- Validation of surface temperature
- Cross validation using measured heating energy demand
- Parametric Study
Ambient Temperature

Measured ambient and indoor air temperature through thermocouple (Starting 19th Nov 2016 12:07PM)
Calibration through Indoor air temperature

Measured vs Simulated indoor air temperature for 7 days period
Calibration Indices

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured Average</td>
<td>18.36°C</td>
</tr>
<tr>
<td>Simulated Average</td>
<td>18.92°C</td>
</tr>
<tr>
<td>Mean Biased Error, MBE (Minute Interval)</td>
<td>-3.03 %</td>
</tr>
<tr>
<td>Mean Absolute Error, MAE (Minute Interval)</td>
<td>3.63 %</td>
</tr>
<tr>
<td>Root Mean Square Error, RMSE (Minute Interval)</td>
<td>0.95°C</td>
</tr>
<tr>
<td>Coefficient of Variation of Root Mean Square Error, CVRMSE (Minute Interval)</td>
<td>5.17 %</td>
</tr>
</tbody>
</table>

![Graph showing the relationship between measured and simulated air temperatures with the equation y = 1.1005x - 1.2887 and R² = 0.9466.](image)

Results and Discussion
Validation of Surface Temperature

Measured vs Simulated inside surface temperature for 7 days period

<table>
<thead>
<tr>
<th>Wall</th>
<th>Measured Average</th>
<th>Simulated Average</th>
<th>MBE (%)</th>
<th>MAE (%)</th>
<th>RMSE (°C)</th>
<th>CVRMSE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (East)</td>
<td>18.50</td>
<td>19.07</td>
<td>-3.12</td>
<td>4.48</td>
<td>1.17</td>
<td>6.32</td>
</tr>
<tr>
<td>B (South)</td>
<td>18.42</td>
<td>19.08</td>
<td>-3.58</td>
<td>4.24</td>
<td>0.99</td>
<td>5.35</td>
</tr>
<tr>
<td>C (West)</td>
<td>18.17</td>
<td>18.83</td>
<td>-3.66</td>
<td>4.17</td>
<td>0.98</td>
<td>5.40</td>
</tr>
<tr>
<td>D (North)</td>
<td>18.10</td>
<td>18.71</td>
<td>-3.36</td>
<td>3.79</td>
<td>0.88</td>
<td>4.87</td>
</tr>
</tbody>
</table>

Calibration indices for 24 days period
Measured set temperature of indoor air due to heating system in case 1 (winter season, Starting 30\textsuperscript{th} Jan, 12:35:29 hrs.)

Power output versus temperature, Source: (TRNSYS 17 Doc.Vol. 5 2012)
Cross Validation through Heating Energy Demand

Cross validation of model 1 through measured hourly heating energy demand (winter season, Starting 30th Jan, 12:35:29 hrs.)

Cross Validation of model 2 (Starting 14th Feb 2017, 16:47:57 hrs.)
## Cross Validation: ASHRAE Standards

**ASHRAE Guidelines for considering a model to be calibrated; based on measured and simulated heating energy demand**

<table>
<thead>
<tr>
<th>Standard / Guideline</th>
<th>Monthly Criteria (%)</th>
<th>Hourly Criteria (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MBE</td>
<td>CVRMSE</td>
</tr>
<tr>
<td>ASHRAE Guideline 14</td>
<td>5</td>
<td>15</td>
</tr>
</tbody>
</table>

Measures to cross validate model at 3 different time periods represented by M1, M2 and M3 (Set Temperature 25°C)

<table>
<thead>
<tr>
<th>Measure</th>
<th>M1 (30th Jan)</th>
<th>M2 (14th Feb)</th>
<th>M3 (20th Feb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured Heating Energy Demand (KJ/h)</td>
<td>3143.4</td>
<td>2747.5</td>
<td>2089.5</td>
</tr>
<tr>
<td>Simulated Heating Energy Demand (KJ/h)</td>
<td>3389.3</td>
<td>2620.0</td>
<td>2066.3</td>
</tr>
<tr>
<td>MBE Magnitude (%)</td>
<td>7.82</td>
<td>4.64</td>
<td>1.11</td>
</tr>
<tr>
<td>CVRMSE (%)</td>
<td>24.59</td>
<td>19.20</td>
<td>21.33</td>
</tr>
</tbody>
</table>
## Parametric Study

Percentage reduction in total annual energy demand of heating and cooling systems for different climate zone cities

<table>
<thead>
<tr>
<th>Region</th>
<th>New Delhi</th>
<th>Dras</th>
<th>Guwahati</th>
<th>Chennai</th>
<th>Goa</th>
<th>Bikaner</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Reduction</td>
<td>0</td>
<td>-183.90</td>
<td>30.82</td>
<td>13.44</td>
<td>35.02</td>
<td>-13.71</td>
</tr>
</tbody>
</table>

Percentage reduction in total annual energy demand of heating and cooling systems for different albedo values applied on the walls of same building

<table>
<thead>
<tr>
<th>Albedo</th>
<th>Percentage reduction (heating)</th>
<th>Percentage reduction (cooling)</th>
<th>Percentage reduction (Total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4 (Base Case)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>0.6</td>
<td>-3.88</td>
<td>5.36</td>
<td>2.40</td>
</tr>
<tr>
<td>0.8</td>
<td>-8.08</td>
<td>10.64</td>
<td>4.65</td>
</tr>
</tbody>
</table>
Parametric Study: Internal Gain (Occupants)

Annual heating and cooling energy demand for different number of occupants

<table>
<thead>
<tr>
<th>No. of occupants</th>
<th>Heating load reductions (%)</th>
<th>Cooling load reductions (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (Base case)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>11.86</td>
<td>-11.10</td>
</tr>
<tr>
<td>4</td>
<td>22.87</td>
<td>-22.62</td>
</tr>
<tr>
<td>6</td>
<td>33.02</td>
<td>-34.58</td>
</tr>
</tbody>
</table>

Comparison of variation in heating and cooling energy demand with increasing number of occupants

Results and Discussion
# Parametric Study: Set Temperature

**Percentage annual energy savings with changing set temperature of cooling system**

<table>
<thead>
<tr>
<th>Set Temperature (°C)</th>
<th>25</th>
<th>28</th>
<th>30</th>
<th>22</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Percentage reduction</strong></td>
<td>0</td>
<td>37.01</td>
<td>57.66</td>
<td>-43.11</td>
<td>-75.23</td>
</tr>
</tbody>
</table>

**Percentage annual energy savings with changing set temperature of heating system**

<table>
<thead>
<tr>
<th>Set Temperature (°C)</th>
<th>25</th>
<th>28</th>
<th>30</th>
<th>22</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Percentage reduction</strong></td>
<td>0</td>
<td>-52.96</td>
<td>-97.19</td>
<td>41.05</td>
<td>62.23</td>
</tr>
</tbody>
</table>
Conclusions

- Calibrated as per ASHRAE standards with MBE and CVRMSE values 1.11% to 7.82% and 19.20% to 24.59%
- Weather variation showed the same building construction in Goa, Chennai and Guwahati with reduced energy demands
- Higher reflectance (0.4 to 0.8) can increase total number of yearly comfort hours from 1037 to 1080 hrs as per ASHRAE standards
- Internal gain analysis showed that increasing number of occupants from 0 to 6 can lead to upto 33% savings in annual heating energy demand
- Increase in set temperature of cooling from 25°C to 30°C leads to 57.7% of energy savings while a decrease in set temperature of heating from 25°C to 20°C leads to 62.2% of energy savings
Scope of Future Work

- Doing a cooling system energy demand measurement and validation for the same LGS unit, which is more relevant to Indian warm and humid climate condition
- Efforts can be made to measure other relevant weather parameters, like humidity, solar irradiation, infiltration etc. to have a closer understanding of actual phenomena
- Doing a comparative study of more prefabricated units to identify best performing unit as per given climate, structural, architectural, ecological and resource constraints
- Validate any design and retrofit strategy by either constructing new buildings or making changes in the existing ones
- Do a subjective assessment of thermal comfort which is based on questionnaire based survey of occupants’ perception of thermal comfort
Acknowledgement

1. Dr. K.K. Bajpayi, Senior Scientific Officer, Structural Engineering Laboratory, IIT Kanpur
2. Mr. Mohit Dwivedi, Jr. Technical Superintendent, Structural Engineering Laboratory, IIT Kanpur
3. Mr. S.K. Jain, General Manager, M/s Hindustan Prefab Limited
4. Mr. N.K. Sharma, Project Manager, M/s Hindustan Prefab Limited
5. Mr. Nitin Kumar, Mr. Tarun Kumar and Mr. Priyesh Pandey, Engineer, M/s Hindustan Prefab Limited
Thank You