

Calibrated Simulation for Energy Performance Evaluation in Large Sized Existing Buildings and Challenges

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Abstract

Existing building stock is huge and consumes significant energy; at the same time, it has significant energy saving potential. Primarily, calibration approach is used to evaluate energy performance. Present study focuses on commercial buildings following calibrated simulation approach to examine building energy performance. Further, energy performance is compared with building code (ECBC, 2007).

Cost benefits analysis is carried out for recommended energy efficiency measures. Also, while developing simulation model and calibration, several challenges are reported and probable solutions are discussed, particularly for chiller performance curves. It is proposed to develop programming interface to feed chiller performance data (full and part load) to the simulation software. The study addresses solutions for large sized commercial buildings in carrying out accurate energy performance analysis.

Introduction

In India, buildings consume more than 40% of the total energy as described in the (ECBC-User Guide, 2009). Further, it is also expected to increase five-fold from 21 billion square feet in 2005 to 104 billion square feet in 2030, (IEEB 2015, 2015). The study show that two-third of commercial and high-rise residential structures that will exist in 2030 are yet to be built, it states that 70% of buildings in India are yet to build. Such rapid expansion presents an opportunity to make a significant contribution to both energy savings and tackling climate change.

Hyderabad is one of the biggest IT hubs in India, only beyond Bangalore. Several IT and ITES (Information Technology Enabled Services) buildings are in operation. Further, central as well as state government authorities have special policy framework to promote Special Economic Zones (SEZ), this is to boost Indian economy. Currently India has more than 200 SEZs in major provenance dedicated to IT/ITeS (SEZ, 2015). India's IT industry amounts to 12.3% of the global market, largely due to exports. Indian IT/ ITES industry revenue was estimated around USD 119.1 billion in 2014-15 as compare to USD 106.3 billion in 2013-14, registering an increase of around 12%.

India is home to several IT/ITeS buildings and due to their 24x365 operations and high occupancy density are energy intensive. Evaluating energy performance of these large buildings is a critical task due to variability in

several areas such as building envelope, lighting, HVAC equipment, plug load/equipment, occupancy and operating schedules. As India moves towards the green revolution in building sector, large facilities are adopting green norms and striving to achieve energy efficiency. Calibrated simulation approach is being used widely for existing buildings (commercial as well as residential buildings) to evaluate energy performance as described by (J.-H. Yoon & Lee, 2001). Primarily calibration is performed using calibration protocol such as IPMVP (IPMVP, 2002), ASHRAE 14-P (ANSI/ASHRAE, 2002) and FEMP (US DOE, 2008).

Calibration methodology is well documented by (Pedrini, Westphal, & Lamberts, 2002) especially for office buildings whereas, (J. H. Yoon & Lee, n.d.) describe how to calibrate simulation model for commercial building. Similarly, auto-tune calibration is also attempted by several authors (New, Sanyal, Bhandari, & Shrestha, 2011).

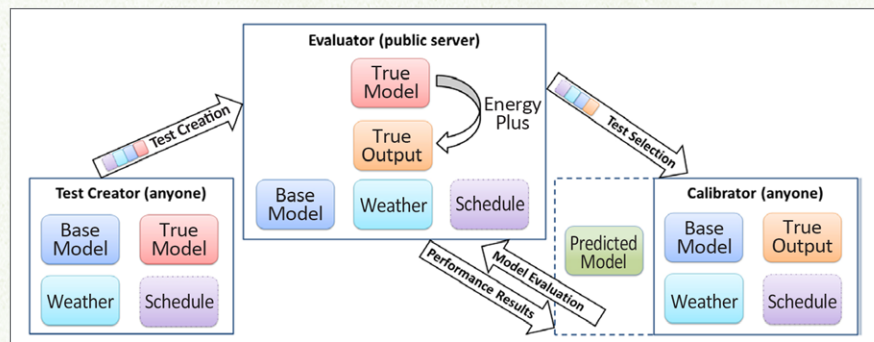


Figure 1: Trinity test system – auto-tune calibration

Auto-tune calibration is developed for small capacity buildings having lesser variability to develop base case and as built case. The methodology addressed the effect of variation in weather data, building envelope, real time energy metering of lighting, HVAC and building energy consumption. However, ITES buildings would have large sized floor plate, several type and application of lighting, HVAC equipment of various type as well as use, variation in occupant density, plug load variation and several others would result in enormous complications for both manual as well as auto-tune calibration. In both the approaches, following errors are estimated between simulation and metered energy consumption for various building equipment, as shown in Equation 1 to equation 4 (Daniela, Anna, Paolo, & Alena, 2015):

$$MBE\ month(\%) = \frac{\sum (S - M)}{\sum M} \times 100\% \quad (1)$$

Where, M and S represent measured and simulated energy consumption during the same time interval.

$$RMSE\ month = \left(\frac{\sum (S - M)^2}{N} \right)^{1/2} \quad (2)$$

Where, N exhibits number of time intervals, here N is 12. The coefficient of variation of the root mean square error is calculated as:

$$Cv (RMSE) = \frac{RMSE\ month}{M\ mean} \times 100\% \quad (3)$$

$$M\ mean = \frac{\sum M}{N} \quad (4)$$

Where, M represents mean energy consumption of all the months. The Permissible error limits are highlighted below:

Table 1: Calibration protocol and permissible error limits

	Monthly criteria (%)		Hourly criteria (%)	
	MBE	CVRMSE	MBE	CVRMSE
ASHRAE Guideline 14	5	15	10	30
IPMVP	10		5	20
FEMP	5	15	10	30

Coakley et al. (2014) published a review article on methods and techniques widely used in calibration (STEM-short term energy monitoring, SIG-signature analysis method, SA-sensitivity analysis, DISSAG-data disaggregation, UQ-uncertainty quantification, BASE-BAYESIAN calibration, ANN-artificial neural network, SEAP-simplified energy analysis procedure). The study stated that calibration is an over-specified and under-determined problem and several discrepancies in inputs and error in data monitoring/ collection are commonly not realized.

It is revealed that HVAC consumes more than (Ghahramani, Zhang, Dutta, Yang, & Becerik-Gerber, 2016) 40% of total building energy therefore, as built definition of chiller in energy simulation plays important role both in the development of base case and as built case (As Is case), for both in manual and auto-tune calibration.

Therefore, in the present study five existing buildings are studied to:

- Evaluate energy performance in existing buildings especially ITES with respect to building code

- Deep retrofit analysis for applicability of energy efficiency measures
- Identify challenges faced while performing modelling, simulation and calibration for large sized floor plate, multi-storey buildings
- Need for further developments especially in the areas of chiller performance and to maximise machine computation

Methodology

The present study evaluates energy performance for five existing buildings using Whole Building Energy Simulation (WBES) (Coakley et al., 2014). Energy Conservation Measures (ECM) specific to the project are studied followed by cost-benefit analysis. Further, the study presents the challenges faced and proposes method to enhance the use of simulation for existing buildings. Figure 2 depicts the flowchart for energy performance monitoring.

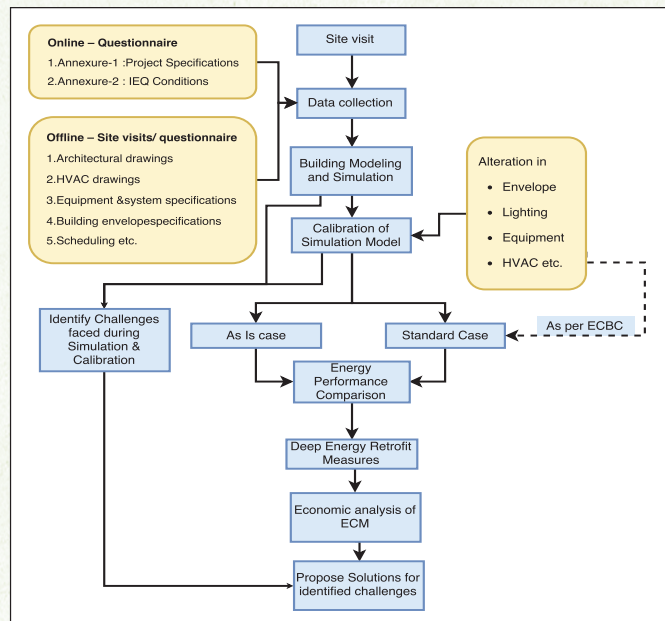


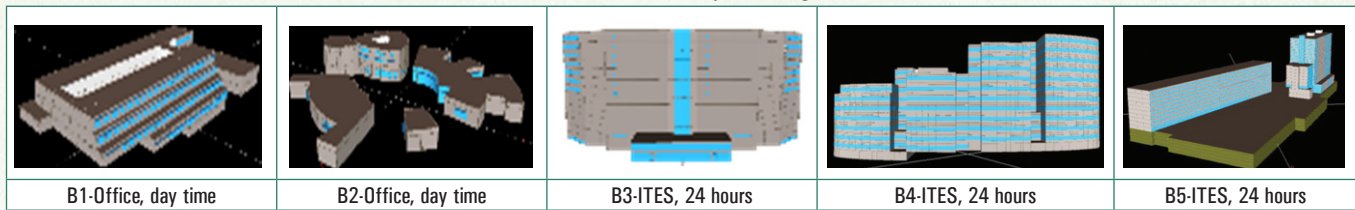
Figure 2: Flowchart – energy performance monitoring

Project Buildings

The study buildings are part of IGBC’s initiative of Energy Performance Monitoring (EPM) service. The objective of the EPM service is to develop methodology for performance assessment of existing building stock. Further, report challenges faces and enable the building industry to adhere the best practices of energy simulation.

Five buildings types were selected for the study. Out of the five, two buildings were small sized and similar in nature of operation, with lower occupancy density and similar type of HVAC system used. As per the study flowchart, building performance data as well as necessary inputs were collected for all five buildings and calibration was performed. However, B1, B2 and B3 were not contributing significantly to the scope of this paper hence, B4 and B5 are studied. Calibration is completed using WBES approach following IPMVP protocol of M&V (Measurement and Verification). Table 2 demonstrates EPM buildings and their nomenclature.

Table 2: EPM study buildings



Building Specifications

Both the buildings B4 and B5 are located in Hyderabad, composite climatic region of India. Building area, lighting, building envelope, plug load, and type of HVAC system are shown in Table 3. B4 and B5 are operated for 24 x 365 wherein weekday occupancy is higher in both the buildings. The overall occupancy density is 8.36 m²/person and 10 m²/person for B4 and B5 buildings, respectively. Additionally, both the buildings are occupied by multiple tenants and managed and operated by their owner. Figure 3 and Figure 4 show simulation model of chosen buildings. Annexure 2 shows the area statement for B4.

Table 3: Specification of buildings, B4 and B5

	B4	B5
Building typology	2B* + G ^f + 10	4B* + G ^f + 9 and G + 16
Area (m ²)	39,847	1,17,105
Occupancy	3946	11,606
Wall U-value (W/m ² °C)	0.341	0.624
Roof U-value (W/m ² °C)	0.500	0.374
Glass U-value (W/m ² °C) and SHGC	2.73 and 0.28	1.76 and 0.23
WWR	49	32
LPD (W/m ²)	0.93	0.7
EPD (W/m ²)	1.25	1.7
Lift load (kW)	140	725
External lighting load (kW)	1.9	14.09
Condenser type	Air cooled	Water cooled
Chiller type	Screw	Screw and centrifugal
TR (Ton of refrigeration)	1730	3404
*Basement, # Ground		

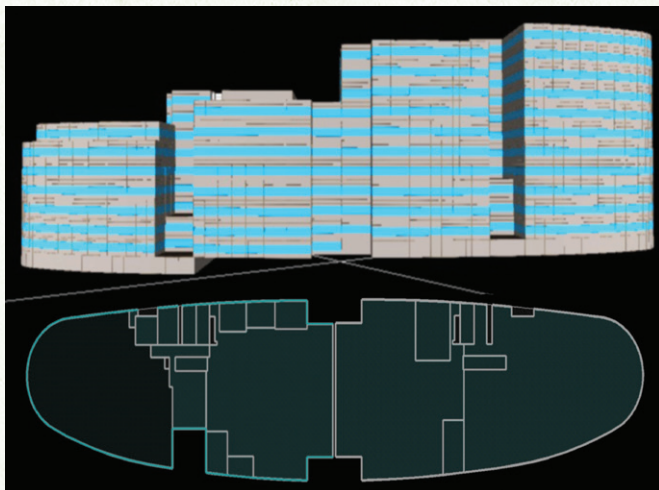


Figure 3: ITES building -B4 and thermal zoning

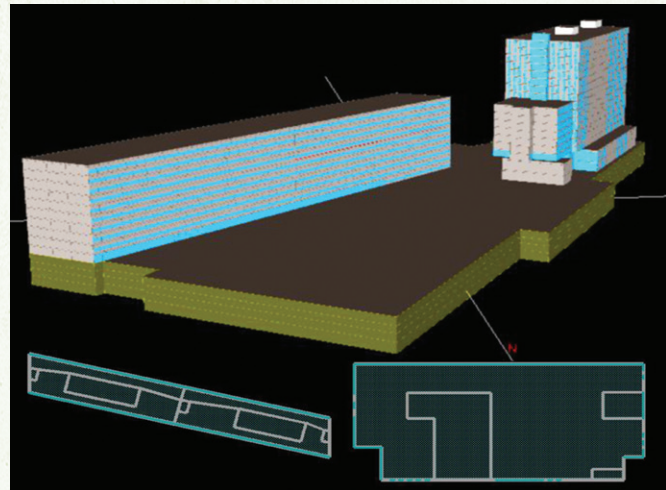


Figure 4: ITES building - B5 and thermal zoning

Modelling and Calibration

As per the flow chart, data was collected through online and off-line questionnaire (Annexure A1) followed by multiple site visits to improve the accuracy of the project data. The offline data collected included architectural and HVAC drawings, equipment and system specifications, details of building envelope and operating schedules. The collected data was utilized in developing simulation model and further in performing calibration. Simulation and modelling was performed using eQUEST (v3.65), mainly due to less time in simulation for large sized buildings. Hourly variations in occupancy, LPD, EPD, thermostat settings, and HVAC system operation were defined. Simulation carried out for 8760 hours. Calibration was done at building as well as component level, primarily for building and chiller energy consumption. Calibration done for permissible errors limits as defined in Table 1.

Due to large variability in operation, large building size, control for downstream and upstream HVAC equipment, variation in activity and prevalence of large numbers of independent interacting variables, it was difficult to achieve an accurate representation of energy performance of the project. Therefore, both B4 and B5 simulation models were simplified as per the zone and control properties. Furthermore, challenges faced and limitations of simulation were recorded to further action, also to aware simulation community and to encourage advanced research. It is now important to mention that existing buildings are in mass and would opt retrofitting measures to meet and exceed local efficiency standards in order to mitigate climate change in the upcoming years. Advancement in simulation and handling

calibration for large sized building would be a concern for existing building stock.

Cost Analysis for Enhanced Energy Efficiency

Seeing energy efficiency potential in existing building stock in India, the application of simulation and calibration is enormous. Approach of calibrated simulation for existing building predicts the energy saving potential accurately. Latest development in building code such as ASHRAE 90.1-2013 (American Society of Heating, 2013) and ECBC-2007 (Conservation & Code, 2007) would be benchmark for energy performance in buildings. Several studies have been carried out that describes how to meet performance benchmark and adoption of new building code and regulation(Xia et al., 2014).

Ruparathna et al. (Ruparathna, Hewage, & Sadiq, 2016) mentioned several ECMs for energy efficiency in existing building including building envelope lighting, HVAC etc.

Result and Discussion

Building Performance

Building B4 is in operation since 2005 and B5 started operation in 2009. While B4 is fully constructed and occupied, B5 is still constructing in phases. Energy consumption of B4 was found to have reduced in the recent years due to retrofitting lighting and HVAC measures, especially installation of LED lighting fixtures and VFD for fan and pumps, evaporative cooling of condenser, etc.

The annual energy consumption of B5 is 19,664 MWh (contract demand is 6329 kVA) in 2015 and is still increasing as newer built spaces are occupied. Whereas, annual energy usages at B4 is 13,003 MWh (3500 kVA). Figure 5 shows energy performance of both the buildings, start from operation.

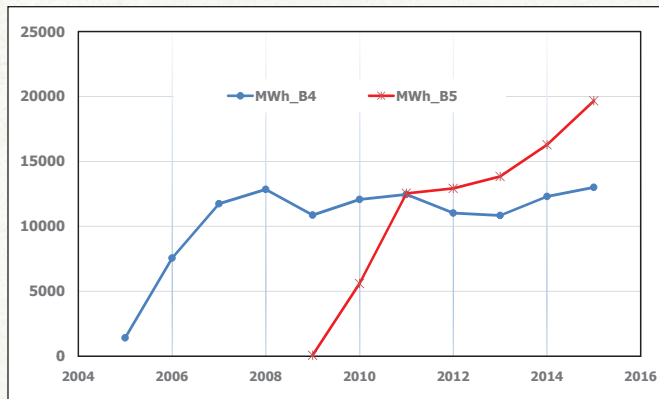


Figure 5: Building energy consumption

Model Calibration Results

Calibration for both the buildings is performed. Building B4 is calibrated for the whole building simulation as well as for the chiller energy consumption. While building B4 is calibrated for only chiller, B5 is calibrated for chiller, pump, interior lighting and AHU consumption. This is possible as the facility monitors the consumption at component level. The calibration errors were well within results as per IPMVP protocol.

Building B4 and Building B5

Table 4 shows permissible error limits before and after model calibration based on annual energy consumption at building level and component level (chiller energy consumption) for B4. It present that obtained error limits found to within permissible limits. Figure 6 represent variation in annual energy consumption from start of operation.

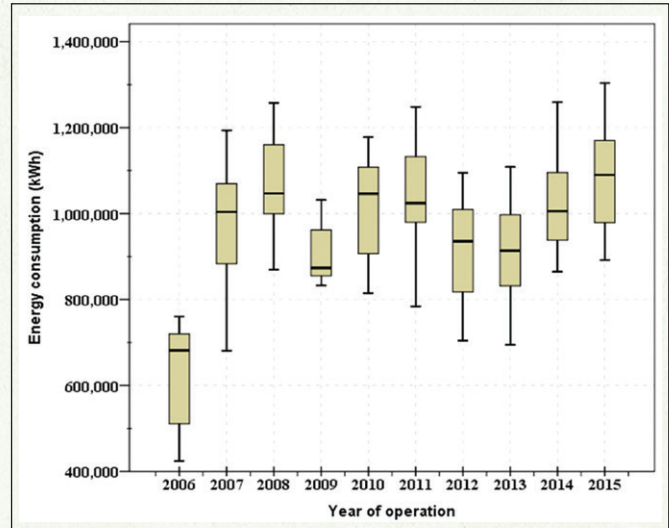


Figure 6: Annual energy consumption – B4

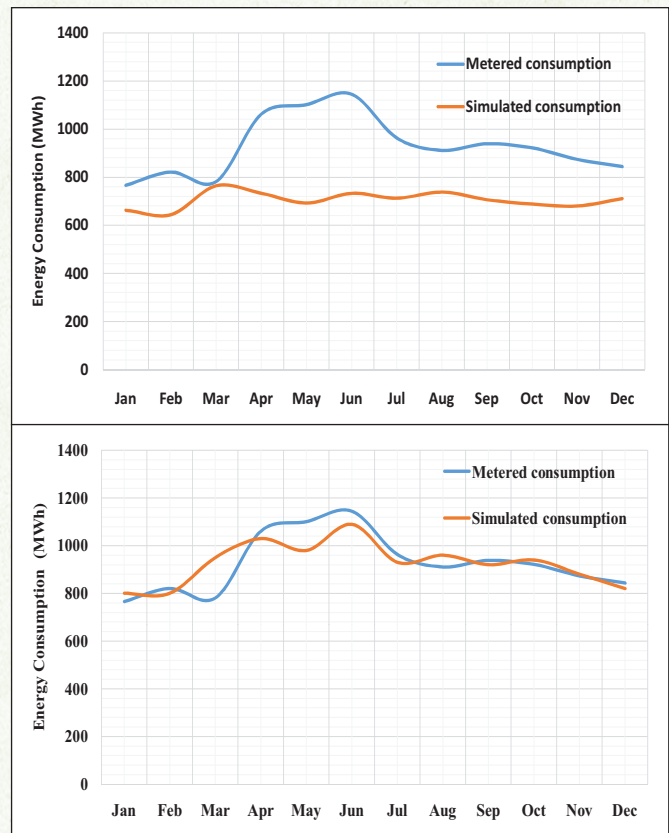


Figure 7: Simulation and metered energy consumption, at building level (before and after calibration) – B4

Table 4: Monthly calibration results -B4 model

Error	Permissible errors	Error at building level		Errors, chiller energy consumption	
		Before	After	Before	After
MBE	± 5%	23.84	2.10	35.49	2.10
CvRMSE	15%	26.76	6.09	38.28	7.06

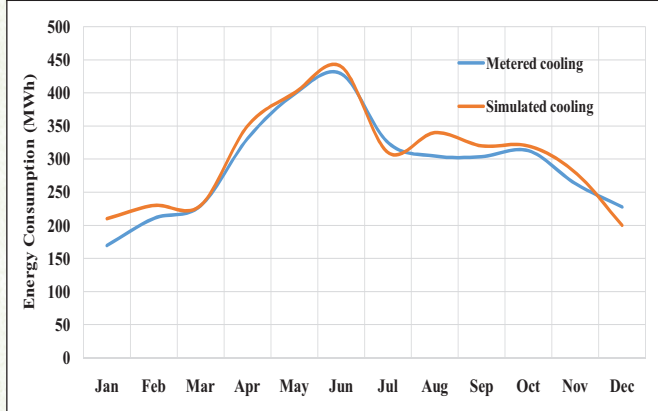
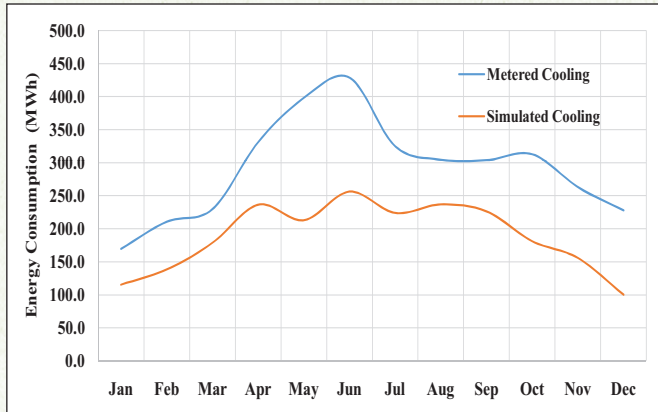


Figure 8: Simulation and metered energy consumption, at chiller level (before and after calibration) – B4

The calibration result for building B5 is shown through Table 5-7. Similar to Figure 7 and Figure 8, comparison between metered and simulation energy consumption were performed for B5.

Table 5: Calibration results - B5

Error	Error at building level		Errors, chiller energy consumption	
	Before	After	Before	After
MBE	27.98	2.96	22.85	1.65
CvRMSE	29.61	8.61	27.61	11.62

Table 6: Pump and lighting calibration results – B5

Error	Errors, Pump energy consumption	Errors, Lighting energy consumption
MBE	2.96	-3.94
CvRMSE	8.61	5.95

Table 7: AHU calibration results – B5

Error	Errors, AHU energy consumption
MBE	0.35
CvRMSE	14.92

Performance Comparison with ECBC

The performance of the building model is compared with the ECBC (Energy Conservation Building Code). ECBC, base case was

developed after calibration of simulation model. Further, As Is case and Base case were compared to estimate energy performance. Figure 6 depicts performance comparison for B4. Base case was found 10% inefficient than the as-is case.

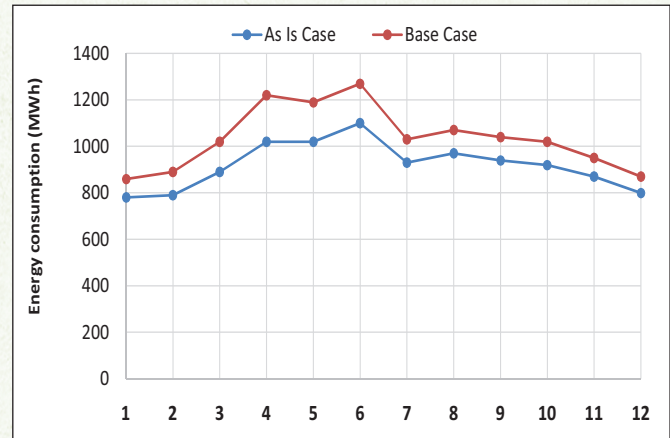


Figure 9: Performance comparison – B4

Comparison for energy consumption between Base case and As Is for B5 was found to be 15% efficient. As B5 has water cooled chiller, performance was found better than the B4.

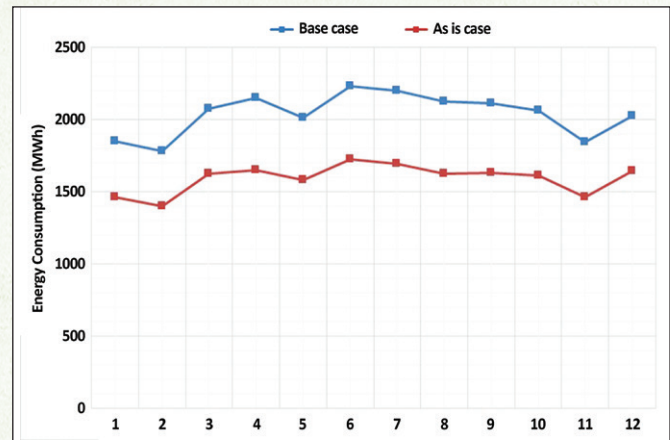


Figure 10: Performance comparison – B5

Cost Economics of ECMs

Several Energy Efficiency Measures (ECMs) were run on calibrated simulation model (as-is case) to estimate the energy saving potential. Primarily, ECMs were selected based on building application. Following measures were suggested:

- Adaptive Thermal Comfort
- High albedo roof (cool roof)
- LED based interior lighting fixture
- LED based exterior lighting fixture
- Evaporative condenser cooling (EcoMesh)
- Installation of VFDs (for AHU, pumps and chillers)
- Retrofitting of energy efficient pumps
- Retrofitting of air-cooled chillers
- Installation of occupancy sensor (facility area), etc.

Table 8: Proposed ECMs and their payback period

S. No.	ECMs	Payback	
1	Adaptive Thermal Comfort	< 1 year	
2	High albedo roof	10	
3	Exterior LED based lighting	2.9	
4	Interior LED based lighting	Phase 1	3.8
		Phase 2	3.8
5	Evaporative condenser cooling	< 1 year	
6	Installation of VFDs to	AHU	2.9
		Pumps and Chillers	1.5
7	Energy efficient pumps	2	
8	Air-cooled to water cooled chillers	8	
9	Occupancy sensors	3	

Cost efficiency was calculated based on the equation 4, based on the market cost of the particular ECM. The cost-efficiency, ϵ_{inv} of an initial investment can be defined as the difference between the energy costs, C_E , and the investment needed to achieve the energy savings, C_{inv} , normalised to the investment:

$$\epsilon_{inv} = \frac{C_E - C_{inv}}{C_{inv}} = \frac{C_E}{C_{inv}} - 1 \tag{5}$$

This definition of cost-efficiency implies values of ϵ_{inv} between -1 and ∞ . The value $\epsilon_{inv} \approx 1$ corresponds to vanishing energy costs, $C_E = 0$ or to a very big capital investment, $C_{inv} \approx \infty$ with almost no energy savings. Almost positive infinity is achieved for very low or vanishing capital investment, $C_{inv} \approx 0$. If C_{inv} is smaller than or equal to the energy cost, C_E , the investment pays back within the considered time-period and $\epsilon_{inv} > 0$. This investment is economically sound and everybody who is able to provide the required capital saves energy and money. However, a cost efficiency of $\epsilon_{inv} < 0$ indicates a financially not rewarding investment.

Table 9: Cost efficiency of the ECMs

S. No.	Energy Conservation Measure	Cost Efficiency
1	Adaptive thermal comfort	4.525
2	High albedo roof	-0.910
3	Exterior LED retrofitting	-0.657
4	LED retrofitting Phase 1	-0.737
5	LED retrofitting Phase 2	-0.734
6	EcoMesh	6.67
7	VFD to AHU	-0.655
8	VFD to pumps and chillers	-0.422
9	Retrofitting air cooled chillers	-0.88
10	Occupancy sensor installation	-0.716

Challenges Faced in Modelling and Calibration

This is one of the core objective to the study to point out challenges faced in the modelling and calibration of simulation model, for large sized buildings. Following are the challenges faced in the present study:

- Modelling of a complex building has to be done in parts due to limitation on thermal zones especially in eQUEST and a limitation of vertexes (120 nos.).
- Limitation of number of thermal zones and vertices for tracing building footprint.
- Obtaining thermal properties of existing building envelope (wall, roof and glass) is crucial. Present study assumes thermal properties of wall and roof based on architectural design. Availability of glass code helped in estimating glass properties.
- Chiller performance at varying load conditions.
- Variability in occupancy and control of different zones of the floor/building.
- Variable temperature setting in case of multi-zone VAV system.
- Efficiency of pump, fan and motors.
- Unavailability of metered data at component level.
- Large variation in occupancy, in B5, occupancy was more than 10,000.
- Chiller performance, it is essential to input actual chiller performance curves to calibrate chiller accurately when chiller performances at part load ratio. Therefore, IGBC took initiative to collect repository of chiller performance curves
- While the facilities mostly have a BMS system in place, most of the equipment is. No.t automatically controlled. Verification of operation procedure is. No.t possible as the operation and sequencing is dependent on the operator.
- Calibrated simulation needs enormous building data, as accuracy of result is fully dependent on the level of calibration of simulation model.

Chiller Performance Curves

Bi-quadratic curve is a function of two independent variables. Input consists of the curve name, the six coefficients, and min and max values for each of the independent variables. Optional inputs for curve minimum and maximum can be used to limit the output of the performance curve. The equation 6 represents the biquadratic curve:

$$Z = C_1 + C_2 * x + C_3 * x^2 + C_4 * y + C_5 * y^2 + C_6 * xy \tag{6}$$

Where, C represents constant and C1-C5 are the coefficients for x and y variables. These coefficients would be calculated from the data sheet shown in Appendix A3, which is collected from the chiller manufacturer for particular chiller (make and model) to estimate the actual performance of the chiller. However, current practice is to use default curves of chiller. Certainly, default curve cannot not give accurate results as per site conditions. Later, an application would be developed though programming interface.

Conclusion

Very few studies have been conducted to estimate energy saving potential in ITES (large sized commercial) buildings. However, due to higher growth of ITES and 24x365 operation, ITES buildings can play significant role in energy efficiency. Calibration of simulation model either manual or auto-tune method may predict energy savings accurately in existing buildings.

Present study found that existing buildings are 10-15 efficient as compared to ECBC, 2007 and implementation of several ECMs could offer further energy saving opportunities. Cost benefit analysis of ECMs was carried out, specific to building. Further, study highlights the current challenges in building modelling and simulation and proposes solution, especially on chillers. The study proposes to collect chiller performance curve at full load and part load. These data shall be used to calculate chiller performance coefficients (Bi-quadratic curve) and inputs shall be used in simulation. This would result in accurate prediction of chiller performance and would establish a practice in building sector.

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Annexure A1: Questionnaire for Data Collection

- 1 **Building occupancy (no. of occupant, occupancy schedule)**
- 2 **Building area**
 - a) Total built-up area
 - b) Air-conditioned and non-air-conditioned area
- 3 **Monthly electricity consumption for last two years**
- 4 **Buildings, architectural drawings (please attach)**
 - a) Floor plan
 - b) Elevation
 - c) Section
- 5 **Air-conditioning system layout (please attach drawings)**
- 6 **Construction details:**
 - a) Wall (layer by layer construction)
 - b) Roof (layer by layer construction)
 - c) Glazing (U-value and Solar Heat Gain Coefficient or type of glass used)

7 Air-conditioning equipment/ system details:

S. No.	Type of Chiller	Chiller Capacity (TR)	Quantity	Chiller COP or kW/TR		Make and Model
				AHRI	Site Conditions	
1	Screw					
2	Centrifugal					

8 Cooling tower details:

S. No.	Cooling Tower	Capacity (TR)	Quantity	Approach (oC)	Range (oC)
1					

9 Air Handling Units (AHU) details:

S. No.	AHU Capacity (CFM)	AHU Capacity (TR)	Motor Capacity (kW)	Air Supply: Variable / Constant volume
1				
2				
Total				

10. Lighting consumption details:

a) Details of Interior Lighting Fixtures			
S. No.	Lighting Fixture	No.	Total (W)
1	xx W		
2			
Total (kW)			

b) Details of Exterior Lighting Fixtures			
1	xx W		
2	xx W		
Total (kW)			

11. Equipment loads

S. No.	No. of Desktop Computers	No. of Laptops	No. of Printers, etc.
1			

12. Server/ data center loads (kW)

13. Total elevator load (kW)

14. Number of pumps and efficiency:

S. No.	Pump Capacity (kW)	Efficiency (%)	VFD	
			Yes	No
1				
2				

15. Operation schedules

S. No.	Schedule Name	From (AM)	To (PM)	Total hours of operation
1	Building operating hours			
2	Occupancy			
3	Interior lighting			
4	Exterior lighting			
5	Fan control (cooling on/ off)			
6	Equipment			
7	Others			

16. Details of exhaust or ventilation fan

S. No.	CFM	Horse Power (HP)	Location (Parking/Other)
1			
2			

17. Hot water requirement (litres/person or total capacity in litres)

18. Installed renewable energy (wind/solar photovoltaic) and capacity

19. A list of energy conservation measures implemented at building including specifications

Annexure A-2: Area Statement – B4

Description	Conditioned Area (sq ft)	Unconditioned Area (sq ft)
Stilt 1 and stilt 2	11152	51484
Ground	40,673	8828
1st Floor	41800	6877
2nd Floor	41800	6877
3rd Floor	41800	6877
4th Floor	41800	6877
5th Floor	32,236	13771
6th Floor	35144	19651
7th Floor	20778	14513
8th Floor	20778	3148
9th Floor	9413	2605
10th Floor	9413	2605

Annexure A3: Chiller Performance Curve (at site conditions) for Calibrated Simulation – HVAC Solution

Manufacturer	XXXX	Chiller Model #	XXXX	
Evaporator flow	612.67	gpm	16.84	ft W.G.
Condenser flow	765.84	gpm	18.04	ft W.G.
Full Load Data at ARI Conditions				
Col A	Col B	Col C	Col D	Col E
CHWS	CWS	PLR	Cooling Cap (TR)	Power (kW)
40	75	100%	249.6	138.0
40	85	100%	234.6	157.4
40	95	100%	218.8	179.9
40	105 (103)	100%	205.6	200.2
40	115	100%	NA	NA
42	75	100%	260.3	139.4
42	85	100%	244.8	158.8
42	95	100%	228.4	181.3
42	105 (102)	100%	216.6	198.9
42	115	100%	NA	NA
44	75	100%	271.3	140.9
44	85	100%	255.3	160.3
44	95	100%	238.4	182.7
44	105 (102)	100%	226.1	200.3
44	115	100%	NA	NA
46	75	100%	282.7	142.5
46	85	100%	266.1	166.8
46	95	100%	248.6	184.2
46	105 (101)	100%	237.7	199.2
46	115	100%	NA	NA
48	75	100%	294.4	144.2
48	85	100%	277.2	163.4
48	95	100%	259.1	185.8
48	105 (100)	100%	249.8	198.1
48	115	100%	NA	NA
50	75	100%	306.4	145.9
50	85	100%	288.6	165.1
50	95	100%	269.9	187.4
50	105(100)	100%	260.3	199.7
50	115	100%	NA	NA

Part Load Chiller Performance with Constant Evaporator Flow (Primary Constant and Secondary Variable)

Manufacturer	XXXX	Model#	XXXX		
Evaporator flow	612.67	gpm	16.84	ft W.G.	
Condenser flow	765.84	gpm	18.04	ft W.G.	
Minimum capacities : without hot-gas bypass, TR			255.3	TR	
With hot-gas bypass, N/A			NA		

Part Load Performance Data						
Col A	Col B	Col C	Col D	Col E		
CHWS	CWS	PLR	C Cap (TR)	Power (kW)	Evap Flow Rate	PD in ft wg
44	85	100%	255.3	160.3	612.7	16.8
44	81	90%	229.8	113.3	612.7	16.9
44	77	80%	204.2	111.2	612.7	16.9
44	73	70%	178.7	92.9	612.7	16.9
44	69	60%	153.2	75.6	612.7	16.9
44	65	50%	127.7	59.7	612.7	17.0
44	65	40%	102.1	49.6	612.7	17.0
44	65	30%	76.6	42.9	612.7	17.0
44	65	23%	58.7	38.3	612.7	17.0
44	65	10%	~	~	~	~

PR: Pressure drop; C Cap: Cooling capacity; CHW: Chilled water temperature, CW: Condenser water temperature, E- Entering, L-Leaving, Evap: Evaporator