M. Tech in Building Energy Performance

Thesis/ Capstone projects

Lighting retrofit of CEPT University: Enhancing visual comfort and reducing energy consumption

The thesis is on lighting retrofit of CEPT University located in India. The research aims to reduce energy consumption and enhance visual comfort of the university. The assessment of the spaces included lighting audits, monitoring of lights, schedule of usage, visual comfort surveys and measurement of illuminance levels. At CEPT University, electricity consumption due to artificial lighting is estimated at 32% of the total due to usage of spaces during the night. Health issues like headache, stressed eyes, glare, and low illuminance levels resulted in more than 50% of the occupants taking breaks for eye recovery. This thesis limits the scope to provide retrofit solutions to meet the requirements of NBC and ECBC for studio, classroom, and private office using the UFC recommendation where appropriate. These three space types contribute to 86% of the lighting energy of the campus. Retrofit solutions were proposed to address the issues identified in the audits and surveys, using technologies from a market survey. The proposed solutions included, lamp sources, fixtures, fixture layouts, interior surface modifications, switching and controls, and task lighting where applicable. These solutions were evaluated for light distribution using Relux lighting simulation software and for cost-effectiveness with a simple payback analysis. The energy savings due to the proposed retrofit are 21%, 44% and 42% for studios, classrooms, and private offices, and the simple payback due to is found 9.5, 3.8, 6.8 years respectively. If all rooms of these 3 space types are retrofitted (67 out of 122 spaces on campus) with the solutions identified, it would amount to an annual energy cost saving of INR 178,670 and annual energy saving of 19,852 kWh for an aggregate payback of 8 years.

Technical potential of integrating evaporative cooling system with mechanical cooling system in hot & dry climate for day use office building in India

The aim of this work is to study the technical potential resulting from the integration of evaporative cooling (direct, indirect and combined) with a mechanical cooling system. This work is limited for the small day-use office space in hot and dry climate of India (refer Annexure - A). For this purpose, an office space (in Ahmedabad) was identified for which access and architectural & air-conditioning drawings and AC system details are available. Envelope, shading, adjacencies, internal gains, operating schedules, ventilation rates are studied. Base Case model was derived with appropriate changes for year-round mechanical cooling. Annual consumption, peak demand, cooling system size are derived for a cooling set point temperature (CSPT) of 25.5°C using simulation software. Evaporative cooling strategies like direct evaporative cooling (DEC), indirect evaporative cooling (IEC) and their combinations (IDEC) are simulated with and without mechanical cooling system. Ideal evaporative air flow rates (to meet the cooling loads) for integrated system are found out. Effect of keeping DEC switched off during humid months and during morning hours in winter months are studied. Effect of using IEC for three humid months and using DEC in remaining nine months of the year is also studied. Finally, Simulations for potential of sensible heat recovery device is also explored in this study. Evaporative cooling systems can be integrated with mechanical cooling system in many combinations. For the similar thermal comfort, hybrid system of mechanical cooling with DEC, IEC and IDEC help reduce VRF cooling system size by 29%, 20% and 38% respectively. HVAC energy is also reduced by 17%, 12% and 26% respectively. Similarly, peak HVAC power is also reduced by 21%,12% and 27%. Use of heat recovery device is justified in case of mechanical cooling only. Heat recovery devices help reduce mechanical cooling system by 31%, HVAC energy by 7% and peak HVAC power by 15%.

Energy and thermal comfort evaluation of low energy cooling systems: A study for the context of office buildings

Low energy cooling systems are designed to consume less energy while providing adequate comfort levels. A report by the Global Buildings Performance Network (GBPN) states that data used for simulation modelling is quite inaccessible in India. It also states that for accurate assessment of potential savings, good amount of reliable field study data is required. This paper evaluates two non-refrigerant based cooling systems with such field study and experimental data for thermal comfort and energy consumption in hot and dry climatic location in India. As a representative location of this climate, experimentation and simulations are done for the city of Ahmedabad. The systems studied are a direct evaporative cooling system and a 2-stage evaporative cooling system. In-field measurements and readings taken in the month of March were used to determine the experimental performance of the system. Energy consumption data inputs were fed into the thermal model of an office building which was modelled as per draft version of Energy Conservation Building Code (ECBC) India. This was performed in DesignBuilder and EnergyPlus combination for comparative performance over a baseline case. This baseline office case was served with a VRV system. Energy consumption savings and thermal comfort observations were reported over this baseline case of simulation model. A long-term thermal comfort survey based on previous perceptions of comfort from 16 occupants served by each of these systems was also reported for understanding. The EPI because of cooling through VRF, DEC and 2SEC is 89, 54 and 55 $kWh/m^2 \cdot yr$ which comes to 40% energy savings in both evaporative cooling cases. The hours not met were 505, 839 and 848 for VRF, DEC and 2SEC respectively. In terms of comfortable hours, DEC meets setpoints better than 2SEC. However, in the broader context, even with cooler effectiveness of 1, the evaporative cooling system does not have the capacity to meet setpoints. i.e. has high unmet hours. If a building owner is interested in providing minimum comfort conditions and is in favourable of adaptive thermal comfort, evaporative cooling system can be installed. DEC can be the priority as it does not have the complexity of installation like in 2SEC and initial cost is also not as much as 2SEC. However, if providing comfort to occupants is the main goal and setpoint requirements are stringent, then evaporative cooling systems – both DEC and 2SEC are not suitable for office buildings where internal loads are very high.

Passive design indices: Quantifying the climatic potential for passive design strategies

The study aims to develop indices to assess the potential of passive cooling strategies for a climate. Cooling accounts for 40% to 60% of summer energy demand in metropolitan cities with hot climates like Delhi, & air-conditioner (AC) sales in India are growing at 30% per year (CEM, 2014). Recommendations based on current climatic zone may not be appropriate as many microclimatic conditions and variations are found in few kilometres range. The currently available climate analysis tools do not explore the inter-relationships between climatic parameters such as dry-bulb temperature, dew point temperature, wind velocity and cloud cover. Earlier work showed that it is possible to develop a weather-data-based classification to map the potential of some basic passive design strategies, such as building orientation, layout, plan, window-wall ratio etc. This study takes that approach forward to establish weather-data-based indices for strategies such as evaporative cooling, comfort ventilation, radiant cooling, earth cooling, and night ventilation. Weather data variables are identified for each strategy. This study uses adaptive thermal comfort models to represent the expected indoor comfort conditions. Typical Meteorological Year (TMY) weather data of 59 Indian cities are analysed to develop the indices. Thermal Autonomy and Discomfort Degree Days are the metrics developed to measure the potential of the passive strategies. An Excel processor and a Power BI user interface tool have been developed. These enable the user to compare the potential for strategies within a climate and compare different locations for their climatic potential for a strategy.

India’s path to low carbon building stock: Estimating energy savings potential for commercial building stock

The buildings sector in India accounts for a third of the total energy consumption of the country. Given the recent and anticipated economic growth in India, the sector is likely to play a more significant role in the energy sector than it currently does. As the building sector follows the “business as usual” construction practice; energy savings potential largely remains unexplored for the country. The aim of this study is to estimate the energy savings potential for two key commercial building types: Offices and Institutional establishments; across all climate zones for the country. Once the representative prototypes are derived, their energy savings potential is estimated by applying energy conservation measures on buildings typologies selected for the study by means of energy simulation. After estimating the energy savings potential for the selected building types, the savings are projected to the selected commercial building stock for the whole country. The project savings are considered for different scenarios, and the best scenario shows the savings of 3000 GWh at national level for office and school types considered here.

Phase Change Material (PCM) application in walls and its impact on energy consumption, thermal comfort and cost benefit analysis in hot and dry climate

The aim of this study is to demonstrate the impact of inside surface PCM application on walls of an office building, towards reducing the overall energy consumption, improving the thermal comfort and analysing the cost benefit potential. The office building is a G+2 floor building, which operates at change-over mixed mode on a seasonal basis. It is located at Ahmedabad, which has hot and dry climate. The heat transmission characteristics of the wall with inside surface PCM is analysed, along with added external XPS insulation, by using the testing facility of Guarded hot box. These experiments are carried out as per the ASTM C1363-05 standard test methods. Simulation software: design builder v4.7 and energy plus v8.3 are used for the whole building analysis. Three combinations of wall assemblies are analysed – internal surface PCM, internal PCM + external XPS and external XPS. The simple payback period of the PCM is calculated using the excel tool. Experimental setup of the guarded hot box validated the PCM operation and effectiveness as envelope component and demonstrated a time lag of almost 9 hours when PCM is used. In case of PCM with melting point 29, the latent heat stored by the thermal mass of the walls is gradually released, leading to the formation of a more stable indoor environment, while in the outdoor environment extensive temperature fluctuations exist. Software simulation analysis showed decrease in cooling energy consumption by 1.54%, The addition of external insulation in combination with internal PCM is increasing the energy savings to almost 4.02%. There was 4% increase in comfort hours (using adaptive comfort model definition) when compared to the baseline buildings with PCM installed at a hot and dry climate of India. Simple payback period calculation is resulting in high payback period of 28 years for PCMs, which can be reduced to 17.5 years combining it with insulation.

Development of affordable sensing and monitoring system for post occupancy building performance evaluation

The building footprint is projected to increase by about 2.3 billion square meters by 2030. The buildings in India consume 33% of the total energy, and it is increasing at 8% per annum (as in 2012). Therefore, studies related to building energy performance and its evaluation are needed in Indian context. Research has shown that intended energy performance is not equal to the actual energy performance. The Learn BPE project aims to identify and understand this energy performance gap of a building. The post occupancy building performance evaluation (BPE) requires continuous sensing and monitoring of the environmental parameters and energy consumption. The commercially available equipment that are used for BPE studies have more than required accuracy and precision for this study. Hence, sensors with higher accuracy and specifications, which cost higher, are built into them. Other than that, such equipment is restricted to proprietary hardware and software, thus limiting their usage, and making them robust. The solution? A methodology for developing an affordable sensing and monitoring solution with optimum accuracy and precision, is tailor made for BPE studies, and is flexible enough to be customized according to ones need.

Quantifying the cooling energy reduction due to three passive strategies for Indian cities

Past studies have quantified the potential of various passive design strategies to achieve thermal autonomy. Bhadra, Vaidya, & Saraf, (2017) have shown that for 60 cities in India, minimum thermal autonomy calculated by using the thermostat set point as the benchmark, is at 12% for night cooling, 75% for evaporative cooling 28% for ground cooling 32% and for radiant cooling. This paper takes that approach further and quantifies the reduction in cooling energy due to three passive strategies, using the CIBSE method with Cooling Degree Days (CDD) for 60 Indian cities. Three passive strategies; Night ventilation, comfort ventilation and evaporative cooling are considered for mixed mode institutional buildings in India. Using the CIBSETM41, the Balance Point Temperature for two different versions of Indian buildings is established; 1) buildings complying with ECBC 2017, and 2) business-as-usual buildings in India. Using these BPT values and the latest TMY files available for Indian cities, the residual CDD for the three passive design strategies and the CDD without passive strategy are calculated. Cooling energy consumption is then calculated for all the cases for the 60 cities. The results are validated by comparing select cases with corresponding Energy Plus simulations. The study provides two versions of realistic BPT for Indian buildings. The results indicate the cooling energy reduction possible due to three common passive design strategies. The results are included in a tool which can be used by building designers in the early design stage, and by policy-makers and equipment manufacturers to understand regional variations.

Energy use prediction of buildings with different methods of calculating SHGC of shaded windows

There exist various methodologies to calculate the effects of exterior shading devices. The ECBC 2017 takes into consideration the impact of shading devices on the SHGC by using a SEF for permanent shading devices. While this is a fixed value for all around the year, “Calculating the effect of external shading on the SHGC of windows” (Kohler et al., 2017) take into consideration a more detailed calculation for the same. They take into consideration the always changing solar radiation and the shaded area variation to calculate the adjusted SHGC for all hours of the year. A weighted average of these values is then taken against the solar radiation for seasonal and annual weighted SHGC indices. Energy simulations also follow different method for the calculation of the impact of the shading devices. This difference in the calculation methodologies will have an impact on the energy use prediction of buildings. This would also result in variation in the seasonal energy use prediction. The study would help in understanding the magnitude of impact of one method against the other in terms of factors like energy consumption and energy savings. It will also help to define how the changes differ due to different climatic conditions and different shading devices. The study will also be able to recommend changes in ECBC depending upon the results.

Evaluating the methodology for performance evaluation of non-residential buildings in India

Buildings consume 33% (24% domestic and 9% commercial) of total energy in India and this is growing at 8% per annum. Reliance on unsustainable energy and increasing demand for energy has led to having an unregulated energy use in buildings in India. Although there have been green buildings built in India, proper implementation and use of the same is not seen. This leads to higher than predicted energy use. There have been limited studies done in India prevailing how to design and operate an energy efficient building. Building Performance Evaluation is essential to reduce this gap and help buildings perform better. Despite the improvements in whole building systems and services and energy efficient building design and implementation, there is a growing gap observed between the intended and actual performance of buildings, leading to higher than expected energy use. The purpose of this study is to understand this performance gap in buildings and develop a methodology for evaluating the gap for the Indian context. The aim of this project is to evaluate the actual performance of buildings through on-site measurements from a building occupant's perspective. The project will develop and validate post-occupancy BPE methodology for Indian buildings through field studies and help reduce the performance gap. The stakeholders benefited from this study are energy experts & designers, building occupant and owners. This will help to close the loop and help feed data for the next design as well as help the existing buildings perform better.

Assessing energy savings and payback period for 2017 version of Energy Conservation Building Code of India

The revised version of Energy Conservation Building Code (ECBC) of India was published in June 2017 after ten years. The new version of ECBC goes beyond minimum compliance, and has two additional levels of ECBC 'plus' and 'super' which include prescriptive requirements and alternative performance goals based on energy use intensity. This paper assesses the energy savings and payback period for the prescriptive of ECBC-2017, minimum compliance, plus and super levels for an office building in Warm and Humid climate of Vishakhapatnam. It also demonstrates alternative cost optimized solutions for these three levels of ECBC. The office building is a real building in design stage according to the current construction trends that do not comply with previous ECBC version 2007 for all building systems. Energy simulations are done in eQuest DOE 2.2, which is an industry standard simulation tool in India. The availability & cost of equipment and material to reach the ECBC 2017 levels is are assessed with a market survey. Since ECBC 2017 is a new code that has yet to be adopted by local building departments, this study shows the energy benefits for ECBC minimum compliance, ECBC plus and ECBC super levels. Further, this paper demonstrates how simulations can be used to find more cost-effective approaches to reach ECBC 2017 performance levels using the whole building compliance approach.

Measuring ventilation rates and leakage in building using the Blower Door method

Best architectural and engineering practice in meeting codes and standards includes keeping the building construction air tight and maintaining the adequate ventilation. But the post occupancy air change rate may not meet design intent, which could be due to multiple factors i.e. infiltration/exfiltration from cracks & openings in the building envelope, change in building construction etc. This results in increase of cooling energy, hence decreasing the buildings performance, also passive strategies like natural ventilation, which work on the principles of difference in pressure driven air flow can vary due to disturbances in pressure. There are different methods to find the ventilation rates, for example tracer gas decay method, injected concentration decay method, blower door method. Later one is a viable option to choose as it is affordable and can be applied on large scale for residential buildings in Ahmedabad.

Quantification of airflow pattern in a naturally ventilated building simulated in a Water Table apparatus

Buildings constitute to about 40% of the energy consumption globally and are responsible for one third of global greenhouse gas emission. Moreover, as, on average people spend 80-90% of time indoors either in office or at home, electrical energy use in building accounts for a significant percentage of total energy consumption. In order to restrict the growth on energy demand, it is important to promote energy efficient strategies in this sector. Passive strategies like natural or hybrid ventilation decrease the dependence on air-conditioning, in turn reducing energy consumption by reducing cooling and electrical energy due to fans. Predicting the performance of naturally ventilated buildings is not simple, as the parameters governing the airflow, such as temperature and wind, are highly variable over time. The different methods available for analysis of natural ventilation designs include: analytical and empirical models, theoretical calculations; scale modelling using wind tunnel, smoke chamber, salt bath and water table; full-scale experiments; simulation: CFD modelling. Out of these types, the water table experiment is inexpensive, easily accessible and provides instantaneous two-dimensional results of airflow patterns in and around the building. The current research focuses on quantifying the qualitative data available from the water table experiment, and developing a metric/tool to quantify air movement within a physical building model simulated in the apparatus. The quantitative results from the algorithm will help to make design decisions in terms of opening sizes, orientation and appropriate positioning of openings in the building. This will be of utility for educational purposes, serving architects, energy consultants and practicing engineers. The flow metric and the algorithm quantify the visual data from the water table and will assist in arriving at design solutions optimized for natural ventilation.

Experimental investigation of the terracotta tubes-based direct evaporative cooling system

Evaporative coolers have many applications in the fields of refrigeration, air-conditioning and power-plants. This system typically work best under dry climatic conditions. Studies have shown direct implications of operating parameters on cooling energy and great potential for energy efficient cooling. The aim of this work is to evaluate the cooling potential of the prototype of the direct evaporative cooling system (designed by AnT studio, Delhi, India) for an indoor application. This is the first attempt to assess the performance of this system by varying the operating parameters like inlet air: velocity, temperature, pressure, relative humidity; water temperature, etc.

Estimation of ventilation rates in classrooms in schools in Ahmedabad

Indoor air pollution being ranked among the top five environmental risks to public health, it is essential for schools to maintain good indoor air quality (ASHRAE 62.1 ventilation rates) to achieve an improved academic performance of students. Good IAQ will provide a better learning environment for the students by giving a sense of comfort and health. The aim of this thesis project is to do on site measurements of the carbon dioxide levels, temperature and humidity in classrooms in schools in Ahmedabad to determine the air flow rate in classrooms. A specific age group of children will be selected and data will be gathered in various schools in the city. The measured ventilation rates will be compared with ASHRAE 62.1-2007 ventilation rates for classrooms.

Evaluation of daylight performance of the new workshop building at CEPT University, Ahmedabad

India is experiencing urbanization more than the expected rate, most of this energy is consumed by artificial lighting, cooling and ventilation through fans. To achieve savings in lighting energy, daylighting can be a useful proposition for energy efficient buildings. It can be a key driver in conserving energy with saving potential up to 45%. As per ECBC 2017, the lighting power density for a workshop facility is 14 W/m^2, which is second highest out of all the LPD requirement and therefore will have very high lighting energy use. This study aims to evaluate the daylight performance by calculating the potential lighting savings (long-term monitoring) and assessing the visual comfort of the newly built workshop building at CEPT University, Ahmedabad, India. The intent behind the study is take field measurements in the workshop to measure illuminance readings, also to do long-term monitoring of the space and perform daylight simulation to assess the annual performance of the workshop wherein most of the investigation will be done since it is cumbersome to take long-term field measurements for a large space.

Retrofitting an existing school building - A case of Aga Khan Academy, Hyderabad

Energy retrofit of naturally ventilated educational building is an effective solution to the thermal discomfort problems of the occupants. The Aga Khan Academy is a residential school, located in outskirts of Hyderabad, India. The school functions in an International Baccalaureate (IB) Curriculum. The building is LEED Platinum rated. The project deals with the retrofit procedure of two building blocks – junior and senior academic blocks with an area of $3608m^2$ and 2750 m^2 respectively, which are naturally ventilated. The procedure contains three steps: First, assessment of the existing conditions through climate analysis, thermal images, measurements & occupant surveys. Second, presenting retrofit design proposal and further optimizing and prioritizing scenarios based on energy simulations and payback time. Third, implementation of retrofit scenarios in the classrooms as a mock up trial and further comparing measured results to the simulation results. The selected measures will be implemented and the thermal environment of the classrooms will be monitored to assess the target achievements.