RESEARCH ARTICLE OPEN ACCESS

Case Studies on Green Institutional Buildings in India

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ABSTRACT
Resource efficiency is a prerequisite to sustainability in the built environment. Various codes, standards, manuals used by public agencies for design and execution of projects, and educational curriculum for graduate studies require integration of green building principles. However, detailed case studies on prevalent building envelope and energy system design strategies in the Indian context are required for education of students and practitioners. This paper documents envelope and energy system details of three public sector institutional buildings in the composite climate zone of India. Since these are government buildings, their environmental performance has been evaluated using the GRIHA green building rating system. The information is published to provide an education tool for various stakeholders.

Keywords - case studies, green building, GRIHA rating

Date of Submission: 01-09-2022 Date of Acceptance: 12-09-2022

I. INTRODUCTION

Detailed green building case studies serve as an important education tool for students and practitioners, and allow for future project planning, and data collection ahead of time. This paper documents building envelope and energy system design strategies implemented by three government GRIHA rated institutional buildings in New Delhi.

GRIHA (Green Rating for Integrated Habitat Assessment) rating framework is an evaluation tool for measuring and rating a building's environmental performance. It facilitates design and evaluates a project through its life cycle including pre-construction, building planning and construction, and operation and maintenance stages. In addition to reducing the greenhouse gas emissions from buildings, GRIHA helps projects to optimise electricity consumption while meeting comfort requirements, reduce dependence on fossil fuel-based electricity and reduce stress on natural resources. Other benefits of GRIHA rated buildings include direct health benefits like reduced air and water pollution.

Green building case studies are instrumental in providing information for enhanced understanding, increasing the body of knowledge, and disseminating information on design strategies around resource efficiency in the built environment. They often outline new solutions to meet various building and energy codes, which students and architects may attempt to understand and advance for their own academic or real-life projects. While several case study publications by the Central Public Works Department (CPWD) -an authority within the Ministry of Housing and Urban Affairs, Government of India, and GRIHA Council provide information on the design approach, highlight overall strategies for GRIHA compliance and provide guidance for projects in India- detailed specifications, and examples to help learn and facilitate code compliance is not available. Popular media articles repeatedly publish and highlight the same buildings, which accentuates the need to dissimilate information about green building projects that have not been documented so far.

In this paper, project case studies include details include building specifications (building size, level of performance as per GRIHA rating, year of construction and occupancy, and cost of the project), and green building features (architectural design, building materials (envelope and interiors), and building energy systems (visual, thermal, and other systems). All three projects are in the composite climate zone and provide useful insights into the prevalent sustainability linked practices in the Indian construction sector.

II. METHODOLOGY

To meet objectives of the paper, approach towards case study selection, data collection, and scope of research is provided below.

Case study selection has been done on the basis such that (i) the building area is more than 20,000sqm (ii) projects are code compliant and have received environmental clearance and GRIHA rating, (iii) located in composite climate zone, (iv) day use, public sector, institutional projects, and (v) more than 40% of occupied built up area is air conditioned.

Four projects located in Delhi meet the above-mentioned criteria, however data was available only for three shortlisted projects.

Data collection for selected buildings is based on:

- Review of primary documents (for construction and operation) including (i) tendered Bill of Quantities (BOQ) issued by the government agency, (ii) final agreement between government agency and contractor, and (iii) final bill under agreement between contractor and government agency.
- Questionnaire based interviews conducted with green building consultants and concerned government officials of each project.

Broad categories for project data collection include:

- General project details including cost
- Envelope details
  - Wall, fenestration, and roof
- Internal lighting
  - Connected lighting load, type of lamp, fixtures, and ballasts, and lighting controls
- Heating, ventilation, and air conditioning
  - Total tonnage, HVAC design parameters, type of HVAC system
- Electrical system design
  - Total connected load, capacity of DG set, and building management system (BMS)

While several parameters contribute to achieving resource efficiency in any given project, this study focuses on documentation of active and passive design strategies that contribute to climate change mitigation and adaptation. Other parameters included in GRIHA rating towards sustainability but excluded for the purpose of this study are outdoor lighting, power related infrastructure (transformers etc.), renewable energy, landscape/ site works, water saving measures during construction, water works inside the building/plumbing, rainwater harvesting, and waste management.

III. RESULTS/FINDINGS

This section describes the three government institutional projects in Delhi identified for detailed case study for the purpose of this research. These buildings represent 'Normal Office' non-residential buildings as per categorisation in the CPWD[1] Maintenance Manual 2019. Since three out of four shortlisted projects have been described, the paper provides useful insights into the prevalent envelope and energy system linked strategies used to achieve resource efficiency in the buildings.

Table 4.1 describes key information about these buildings. Subsequent sections describe the detailed building characteristics, level of GRIHA provisional rating, year in which the project was completed, and total project costs incurred. To systematically understand the case study buildings, their details have been presented in two sections:

- Building specifications: Explains the building's size, level of performance as per GRIHA rating, year of construction and occupancy.
- Green building features: Details the architectural design, building materials (envelope and interiors), and building energy systems (visual, thermal, and other systems). This section also provides information on compliance with various components of the Energy Conservation Building Code (ECBC) 2007 namely, U value for wall assembly, external window assembly and lighting power density.

Table 1: Key information about the case studies; Source: Compiled by Priyanka Kochhar

Building	**Built-up Area**	**Total Project Cost**	**Date Completed**	**Salient Features**
Building 1	31,400 m^2 • +7 3 basements	Rs.199.88cr (Rs.63,670/sqm) • Civil:63.45cr (31.74%) Elec.:23.51cr (11.76%)	2014	•GRIHA 5 Star (provisional) • Optimal North-South orientation • WWR= 17% • Daylight integration • Self-shading • EPI: 39.29kWhr/m2/annum • 930KWp rooftop solar power plant • Chilled beams for air conditioning • Geothermal heat exchange system • LED fixtures+ sensors • Robotic car parking in

[1] Central Public Works Department, Government of India responsible for execution of public works for Government of India

				basements • Energy saving regenerative lifts • Pervious paving • Flyash based construction material
Building 2	45,761m^2 • +4 1 basement	Rs.115cr (Rs. 25,130/sqm) • Civil:100.6cr (87.47%) Elec.: 3.35cr (2.91%)	2015	• GRIHA 4 Star (provisional) • North-South orientation • WWR= 23.5% • Daylight integration • Strong shading strategy • EPI: 59.06kWhr/m2/annum • 5MWp solar system on campus • CFL and T5 fixtures • Flyash based material
Building 3	76,188m^2 • +5 3 basements	Rs.405cr (Rs. 53,160/sqm) • Civil: 137cr (33.82%) Elec.: 66cr (16.29%)	2017	• GRIHA 5 Star (provisional) • WWR= 35.4% • Daylight integration • EPI: 43.5kWhr/m2/annum • 202KWp rooftop solar PV • LED fixtures+ sensors • Pervious paving • Flyash based material

3.1 Building 1

Building 1 is the office building for one of the Central Ministry, Government of India. The eight-storey office building with three basements is approximately 31,400 m2 and is in Jor Bagh, New Delhi. It is a new building completed in 2013, and occupied in 2014, designed primarily to house open-plan offices with meeting rooms. Built at a cost of approximately Rs. 200 crores, 64% of the super structure is air conditioned and occupied by 600 employees, including two Ministers.

The superstructure includes a committee room, seven conference rooms, an auditorium with 125 seating capacity, a roof garden, gymnasium, yoga room for recreation, a cafeteria, kitchen, and executive dining hall. It also supports a roof top solar power plant of 930kW capacity. The basement includes a fully automated robotic parking for 330 cars and services, including the air conditioning plant, electrical substation and transformers, firefighting pump house, sewage treatment plant, diesel generator sets and uninterruptible power source (UPS).

With longer sides facing North and South, the front and rear blocks of the building are separated to create a large courtyard. The two blocks are connected at the 4th floor level with corridors. There is a huge entrance atrium, with a clear height of four stories on the front block. The building has large span trusses at the terrace, and space frame in the central courtyard to support solar panels.

Figure 1: building 1 image; source: Priyanka Kochhar, assisted by Kanika Trivedi

3.1.1 Building specifications

The fabric of the building was designed to be highly insulated, and the architectural design promoted passive design. Narrow floor plates, connected by atriums and cut-outs, created an interconnected and open environment, provided deep natural light penetration, and enhanced natural ventilation by creating a stack effect. Fabric U-values (W/m2K) were as follows: Wall: 0.37; Window: 1.40; Roof: 0.26; and design airtightness was 5 $m^3/hr/m^2$ @ 50 Pa.

HVAC systems design

Heating was designed to be primarily provided by heat pumps that can produce simultaneous heating and cooling and was distributed to the building via heating and cooling buffer vessels. The heat pumps were also designed to satisfy the cooling needs of the IT server room. But the heat pumps only operated if there was a heating demand in the building. In the absence of heat demand, a free cooling chiller satisfied the cooling needs, via a chilled water buffer vessel. When the amount of heat produced by the heat pumps was insufficient for the building heat load, in the event of low external temperatures, then the additional heat needed was to be provided by modular condensing gas-fired boilers which were designed to meet peak loads and give full back-up. When working in heat transfer mode, the heat pumps had a maximum combined COP (40% cooling / 60% heating) of 6.5. The energy efficiency ratio (EER) (cooling mode, full load) was 2.75 and Heating COP (full load) was 2.31. The boiler seasonal efficiency was 95.6%.

There were two heating loops planned, one constant temperature loop that ran at a fixed flow temperature of 45°C and weather-compensated variable temperature loop that ran at a maximum of 65°C during boost time. Underfloor radiant heating was provided in circulation and communal areas and trench heaters supplied heating to all offices and meeting rooms. Cooling for space conditioning, only provided for meeting rooms, was supplied by chilled beams.

Natural ventilation was the primary form of ventilation and was provided by vents which were controlled via a BMS, based on CO_2 concentration and air temperature. A night-cooling strategy was specified to keep the open-plan offices cool in summer. Manually openable vents were also provided. Toilets and other enclosed occupied spaces had dedicated mechanical exhausts.

3.1.2 Green features of the building

Building material

- Brick work for walls

All the outer walls on Northern and Southern sides of the building are double wall units with rockwool insulation in between. The outer walls are made of AAC (Autoclaved Aerated Concrete) blocks and the inner walls with FaLG (Flyash Lime Gypsum) bricks. 50mm thick rockwool insulation is provided between the outer and inner walls.

The outer walls on Eastern and Western sides of the building (where most of the non-occupied spaces and select offices are located as thermal buffer) are made of single walls with rockwool insulation on the inner side, covered with gypsum board.

All other outer wall facing the internal courtyard are single walls with AAC blocks to provide better thermal insulation. The internal walls and those around the service shafts are provided with FaLG bricks to ensure adequate fixity for doors, windows, and service lines.

The entire vertical building envelope is thermally insulated, and all filler walls are fly ash based. The U -value of wall assembly of the insulated building envelope is 0.37 W/m2K (ECBC 2007 requirement: 0.44 W/m2K).

- Wood and PVC work for fenestrations

All windows in the building are Un-plasticised Poly Vinyl Chloride (UPVC) windows with double glazed units. UPVC windows use recycled material, have low embodied energy, and low thermal conductivity. The hermetically sealed double-glazed units (made of 6 mm thick outer toughened offline coated advanced solar control and thermal insulation glass + 12 mm dehumified air gap + inside 6 mm thick heat strengthened clear float glass) provide high visual transmission and lower the heat gain.

To meet the GRIHA rating requirement of heat load reduction and achieve 40% energy savings, the U-value of external window assembly is 1.5 W/m2K (ECBC 2007 requirement: 3.3 W/m2K). The visual light transmittance (VLT) is 0.59. With a Solar Heat Gain Coefficient (SHGC) of 0.31 of double glazing and appropriate shading design, achieved SHGC of fenestration is 0.25.

- Roof

The roof assembly in the building has been provided with a three-layer insulation system, bringing down the U-value of the assembly. After laying the conventional brick koba treatment on the roof top, the surface is subsequently covered with PUF (Poly Urethane Foam insulation) and heat reflective tiles. A terrace garden to slow down run off, keep the building cool and ameliorate the urban heat island effect is also provided on the 7th floor of the building.

Building energy systems

- Indoor lighting and control sensors

The lighting system of this building is designed with LEDs, T5 lamps and sensor controls, in such a way that the Lighting Power Densities (LPDs) in all spaces are much less than the benchmark values specified in ECBC 2007. Daylight sensors (lux level sensors) are provided in all areas along the outer building envelope where daylight is available most of the time. Occupancy (motion) sensors are used in all areas located away from the outer building envelope, where natural daylight is not available. All the workstations and toilets in the building are with occupancy sensors with turnoff time of 5 minutes in steps of 1 minute, covering a functional radius of 6m for each sensor.

Luminous efficacy of each type of LED lamp fixture used is varying from 50 to 87 lm/W against the GRIHA benchmark of 50 lm/W and that of T 5 lamps is 57 to 85 lm/W.

- HVAC

64% of the building superstructure is air conditioned and designed for both cooling and heating. The air conditioning load is estimated to be 400 TR for which two water cooled screw chillers (1 working + 1 standby) of 240 TR each and one 200 TR water screw chiller have been installed for chilled beam system.

The chilled beam system is designed to heat or cool large buildings where pipes of water are passed through a “beam” (i.e. heat exchanger) suspended a short distance from the ceiling of a room. As the beam chills the air around it, the air becomes dense and falls to the floor. It is replaced by warmer air moving up from below, causing a constant flow of convection and cooling the room. Heating also works similarly.

This is the first time that chilled beam air conditioning is provided in any government building in India. The technique has lower operating costs, is noiseless, requires reduced air distribution duct networks and less ceiling space as compared to forced air HVAC systems that lead to less building height.

The vertical closed loop system of geo-thermal heat exchange has been used to bring about load reduction on the HVAC system. The geothermal cooling system utilises the advantage of difference between ambient temperature and the temperature below ground level. It is a vertical loop system with a network of 32mm diameter HDPE (high-density polyethylene) U-loops lowered into 180 bores (80 m deep) spread along the building premises, resulting in reduction of 160TR load on cooling tower with subsequent reduction in use of water.

This technique has been adopted for the first time in a government building in India.

- Electrical

The total electrical load of the building is 830kW. There are two 1000KVA dry type transformers and one step up dry type transformer of capacity 1250 KVA provided to supply power from solar panels to NDMC[2] grid to make it net zero building.

Two 500 kVA, 415 volts, 50Hz, radiator cooled diesel generator sets for emergency power are provided. Further, UPS power has been provided to support critical service such as emergency lighting, power points for workstations, security system and building automation system and NIC server room. Three 120kVA in parallel and one 60kVA UPS have been provided for server equipment.

An integrated building management system to control and monitor the building’s mechanical and electrical equipment such as HVAC, power system, lift, indoor air quality etc has also been provided.

3.2 Building 2

Building 2 is an important building in an autonomous public research and engineering institute located in Hauz Khas in South Delhi. The multi-storey (B+G+5) building is a composite structure of RCC and structural steel. It comprises lecture halls with 500, 300, 150, 60 and 30 seating capacities, laboratories for physics, chemistry, biology, applied mechanical, computers, humanities, and design studio along with an auditorium with 500 seats, and conference rooms. The building is divided in 5 blocks, A, B, C,D & E by construction/ seismic expansion joints and has been designed to accommodate all undergraduate and post graduate students.

Figure 2: building 2 image; source: Priyanka Kochhar, assisted by Kanika Trivedi

The whole building is on raft foundation of RCC and designed as compact building to save energy. It is centrally air conditioned and meets GRIHA 4 Star compliance on energy and other standards. Select features of the building are as follows:

- RCC framed structure with shear walls
- Cavity walls and double-glazed glass
- Aluminium doors and windows
- External dry cladding in sandstone
- Fire resistant structural glazing and aluminium composite panel
- Vitrified tile in labs, kota stone in corridor and granite in foyer
- Acoustic treatment of lecture halls
- Fire alarms, sprinklers, and wet risers
- Adequate number of lifts in three blocks
- Centrally air-conditioned classrooms and labs
- Smart classrooms with projectors and audio video facilities

Block A comprising central foyer and entry area has a double height (10.75m) opening. This block is circular in shape and the RCC structure has circular beams that are curved in plan along with circular columns (10.75m height).

Block B is circular in shape and comprises the lecture halls. Due to the long spans of lecture halls (24.3mx21.15m), structural steel plate girders that rest on shear walls have been provided. Built up sections of structural steel are used as primary and

[2] New Delhi Municipal Council (NDMC) is the municipal council of the city of New Delhi.

secondary (beams) members. Primary members (plate girders) are supported by RCC shear walls. It consists of 3 lecture halls of 300 capacity on the ground floor, 4 lecture theatres of 150 capacity and student lounge on the first floor, 4 lecture theatres of 150 capacity and student lounge on the second floor, 4 lecture theatres of 150 capacity and 3 classrooms of 60 capacity on the third floor, and 9 classrooms of 60 capacity and 9 classrooms with 30 people capacity on the fourth floor.

Block C is the laboratory block which is an RCC structure in rectangular shape (45.08mx17.65m). The height of each floor is 4.2m, where the main structural members are beams and columns. There are 5 laboratories on each floor.

Block D has a composite structure of structural steel and RCC. Due to the long span (42.04mx20.74m), height (8.54m) and circular shaped auditoriums, built up sections of structural steel have been provided as primary and secondary members. Plate girders are supported by shear walls. It comprises an auditorium of 500 capacity on the ground floor (up to mezzanine floor roof slab), an auditorium of 500 capacity on first floor (up to second floor roof slab) and 2 laboratories on the third floor.

Block E consists of ramp area in between C&B blocks and B&D blocks.

3.2.1 Building specifications

Built on a 19,690sq m site inside the 320 acres campus, the building has been designed to accommodate a floating occupancy of 2200 students and faculty. It has a total built up area of 45,761sqm out of which about 40% is air conditioned. Building envelope U-values (W/m2K) were as follows: Wall (thick stone cladding+230mm flyash brick+115mm flyash brick+plaster): 0.766; Window (i.e. glazing in air conditioned area): 1.9 with VLT of 0.39 and SHGC of 0.28; Roof assembly (RCC slab with 50mm fibre glass wool +150mm brick coba): 0.596.

The building design ensures daylight to 51.6% of occupied areas and artificial lighting is provided using T5 lamps with electronic ballasts and CFLs. The LPD achieved is better than ECBC requirements. The HVAC systems have been designed to maintain a room temperature of 24 ± 1°C. The total cooling load is 550TR, where 3x275 TR variable air volume with water loop chiller system (2 working+1 standby) have been used. The total load of electrical systems is 1271kW, and an integrated building management system is also provided.

3.2.2 Green features of the building

Building material

- Brick work for walls

The outer walls of the building comprise a cavity wall made of 230mmflyash brick and 115mm flyash brick clad with thick stone on the external side and plaster on the internal side, resulting in U -value of 0.766 W/m2K (ECBC 2007 requirement: 0.44 W/m2K).

- Wood and PVC work for fenestrations

24 mm thick double glazed hermetically sealed windows are provided in the Northwest/ Southwest sides of the building. Sun louvers are also provided to reduce the cooling load. Glazing U-value for air-conditioned area: 1.9 W/m2 °K and for common/ non-air-conditioned area is 5 W/m2 °K. Glazing Solar Heat Gain Coefficient (SHGC) for air-conditioned area is 0.28 and for common/ non air-conditioned area is 0.43. Glazing Solar Coefficient for conditioned area is 0.32 and that for common/non-conditioned area is 0.49. the total window to wall ratio is 23.5%. To meet the GRIHA rating requirement the visual light transmittance (VLT) is 0.39.

- Roof

The roof assembly has been provided with reinforced cement concrete slab, with 50mm fibre glass wool insulation and 150mm brick coba.

Building energy systems

- Indoor lighting and control sensors

The lighting system of this building is designed with T5 lamps with electronic ballasts and CFLs to achieve Lighting Power Density (LPD) of 1.5 W/ ft2 for Lecture Theatre/Classroom; 1.0 W/ ft2 for Equipment Room and 0.5 W/ ft2 for Miscellaneous Areas and meet ECBC 2007 recommended levels in all spaces.

- HVAC

40% of the building superstructure is air conditioned and designed for central cooling. The air conditioning load is estimated to be 550 TR for which 3x275 TR variable air volume with water loop chiller system (2 working+1 standby) have been installed.

- Electrical

The total electrical load of the building is 1271kW. Two diesel generator sets (500kVA+750kVA) are used for emergency purposes or during power failure.

There are three 2000KVA dry type transformer and one 1000kVAtransformers provided on site.

Further, UPS power (100kVA) and integrated building management system has been provided.

3.3 Building 3

Building 3 is an Indian public sector banking and financial service company, with its headquarters in New Delhi, India. It is a Public Sector Undertaking (PSU) working under Central Government of India regulated by Reserve Bank of India Act, 1934 and Banking Regulation Act, 1949.


Figure 3: building 3 image; Source: Priyanka Kochhar, assisted by Kanika Trivedi

3.3.1 Building specifications

Built on a plot size of approximately 5acres, the office has been designed for about 1650 employees, covering a built-up area of 76,188m2 across six floors and three basements. About 70% of the superstructure is air conditioned. While it was designed as a net-zero building, the final project has received GRIHA 5 Star (provisional) rating.

The building is composed around the central axis that emerges from the metro station through the park into the centre of the site. Bridged floors across the axis are created at ground and top levels for corporate floor, café, and multipurpose halls. The opening up of the entire centre of the building breaks down the scale of the large building into smaller elements. There is a six-storey high circular glazed cylinder at the end of the axis that accommodates the building gallery, VIP lounges and special conference rooms. Opening of the centre creates a strong venturi effect that draws the south-west winds into the atrium, making natural cooling effective for several months through the year.

3.3.2 Green features of the building

Building material

- Brick work for walls

The outer walls of the building are double wall units with extruded polystyrene as insulation in between. The outer walls are made of 200mm AAC (Autoclaved Aerated Concrete) block and the inner walls of 100mm AAC block. 30mm extruded polystyrene is provided between the outer and inner walls, resulting in U -value of 0.39 W/m2K (ECBC 2007 requirement: 0.44 W/m2K).

- Wood and PVC work for fenestrations

All windows in the building are Un-plasticised Poly Vinyl Chloride (UPVC) windows with double glazed units.

To meet the GRIHA rating requirement of heat load reduction, the U-value of external window assembly is 1.48 W/m2K (ECBC 2007 requirement: 3.3 W/m2K). The visual light transmittance (VLT) is 0.49. With a Solar Heat Gain Coefficient (SHGC) of 0.22 of double glazing and appropriate shading design, achieved SHGC of fenestration is 0.23.

- Roof

The building has a unique roof design. The roof plane is broken into four panels, comprising two lower side panels that reflect the slightly tilted geometry of the building plan below, and two raised panels that cover the atrium.

The roof assembly has been provided with 250mm reinforced cement concrete slab, with 75mm XPS insulation and tiles finish.

Building energy systems

- Indoor lighting and control sensors

The lighting system of this building is designed with LEDs and sensor controls, to achieve Lighting Power Density (LPD) of 0.60W/ft2 for office floors and meet ECBC 2007 recommended levels in all spaces. Daylight sensors (lux level sensors) and occupancy (motion) sensors have been installed in the building.

- HVAC

69% of the building superstructure is air conditioned and designed for central cooling. The air conditioning load is estimated to be 660 TR for which three water cooled chillers (2 working + 1 standby) of 375 TR each and one 100 TR chiller have been installed.

- Electrical

The total electrical load of the building is 2195kW. Electricity is sourced from BSES Rajdhani Power Limited[3]. Diesel generator sets are used for emergency purposes or during power failure. 200kWp solar rooftop plant has also been installed.

There are three 1000KVA dry type transformer and four DG sets with rating 2x1000kVA (gas based), 500kVA (diesel based) and 380kVA (diesel based) capacity.

Further, UPS power has been provided to support critical service such as emergency lighting, power points for workstations, security system and building automation system and server room.

An integrated building management system to control and monitor the building's mechanical and electrical equipment such as AHUs, TFAs, chillers and electrical system has also been provided.

3.4 Summary of Case Studies

3.4.1 Building Envelope

A summary of building envelope specifications of the three case study buildings is provided below:

[3] A Joint Venture of Reliance Infrastructure Ltd. & Govt. of National Capital Territory of Delhi.

Table 2: Case study building envelope specifications; Source: Compiled by Priyanka Kochhar

Envelope	Wall	Glazing	Roof
	• 200mm AAC Block + 50mm rockwool+FaLG bricks • U -value 0.37 W/m2K	• U-value of external window assembly: 1.5 W/m2K • VLT: 0.59 • SHGC: 0.31	• Brick koba treatment+PUF+heat reflective tiles • U value of roof assembly: 0.26 W/m2K
	• Thick stone cladding+ 230mm flyash brick+ 115mm flyash brick+ Plaster • U-value: 0.766 W/m2 K	• U-value of glazing for air conditioned area: 1.9 W/m2 °K • VLT: 0.39 • SHGC: 0.28	• RCC slab+50mm fibre glasswool+ 150mm brick coba • U value of roof assembly: 0.596 W/m2 K
	• 200mm AAC Block + 30mm rockwool+ 100mmm AAC Block • U -value 0.39 W/m2K	• U-value of external window assembly: 1.48 W/m2K • VLT: 0.49 • SHGC: 0.22	• RCC slab+ 75mm XPS+ tiles • U value of roof assembly: 0.31 W/m2K

3.4.2 Building Energy Systems
A summary of building energy systems of the three case study buildings is provided below:

Table 3: Case study building energy system details; Source: Compiled by Priyanka Kochhar

	Lighting	HVAC Systems	Electrical System
Bldg 1	• Daylight integration (75%occupied areas daylit) • T5 lamps with electronic ballasts • LEDs • Daylight/lux level sensors • Occupancy/motion sensors • LPD: Better than ECBC requirement •10% of total energy demand	• Room temperature of 26 ± 1°C • 64% superstructure air conditioned • Cooling load: 400TR 1. 2x240 TR water cooled screw chillers (1 working+1 standby) 2. 160TR Geo Thermal system with chilled beam system 3. 200 TR water screw chiller for chilled beam system. •35% of total energy demand	• Total load: 830kW • Transformers: 2x1000kVA dry type + 1x1250kVA stepup to supply from solar grid to NDMC • DG sets: 2x500kVA radiator cooled • UPS • Integrated building management system
Bldg 2	• Daylight integration (76.6%occupied areas daylit) • LEDs • Daylight/lux level sensors • Occupancy/motion sensors • LPD: Better than ECBC requirement •7% of total energy demand	• Room temperature of 26 ± 1°C • 69% superstructure air conditioned • Cooling load: 660TR 1. 3x375 TR water cooled chillers (2 working+1 standby) •84% of total energy demand	• Total load: 2195kW • Transformers: 3x1000kVA dry type • DG sets: 4 (2x1000kVA gas based+ 1x500kVA diesel based+ 1x380kVA diesel based) • UPS • Integrated building management system
Bldg 3	• Daylight integration (51.6%occupied areas daylit) • T5 lamps with electronic ballasts • CFLs • LPD: Better than ECBC requirement •25% of total energy demand	• Room temperature of 24 ± 1°C • 40% superstructure air conditioned • Cooling load: 550TR 1. 3x275 TR variable air volume with water loop chiller system (2 working+1 standby) •16% of total energy demand	• Total load: 1271kW • Transformer: 1000kVA +3x2000kVA • DG sets: 500kVA+750kVA+ •UPS: 100kVA • Integrated building management system

IV. DISCUSSION

Based on the description of three government institutional projects in Delhi, this paper provides information on prevalent building envelope and energy system design strategies in the composite climate zone of India. Corresponding information on Energy Performance Index (EPI) and level of GRIHA rating for each case study building is also presented in Table 4.1.

Active and passive building design features incorporated in Building 1 (completed in 2014) in were taken up under a special provision because the CPWD schedules and specifications did not incorporate GRIHA rating requirements in 2007 when the project was initiated. Design and construction of the building paved the way for several GRIHA rated green buildings to be constructed by the government and private entities towards meeting India's climate change commitments.

Active and passive principles of design followed by Building 2, including reduced air-conditioned area, may be adopted by other upcoming academic buildings as well. While active and passive principles of design followed by Building 3 may be adopted by other financial institutions and multinational organisations.

From an education perspective, the paper provides details of various components and indicates compliance with relevant section of the ECBC including U-values for external wall and window assemblies, and lighting power densities.

In summary, the research paper documents three building case studies to achieve the following objectives:

- Provide an education tool for students and practitioners, and
- Showcase envelope and energy system details, vis a vis compliance with ECBC, building performance and level of GRIHA rating.

V. CONCLUSION

Given that sustainability is an important part of design and construction of public institutional projects, and that relevant parameters are dovetailed and implemented in the Works Manual for all public projects, detailed documentation of project case study for educational purposes is recommended.

Openly available information on envelope (including wall, window, and roof), energy systems, and building performance shall enable a clearer understanding and may facilitate incorporation of further details during invitation of tenders and encourage bidding teams to propose the most environmentally effective options for implementation.

In addition to information on envelope and energy systems, strategies for renewable energy, water management, and sustainable building materials may be included for documentation of future case studies.

Acknowledgements

We are grateful to CPWD, the GRIHA Council and SPA Delhi for facilitating data collection.

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