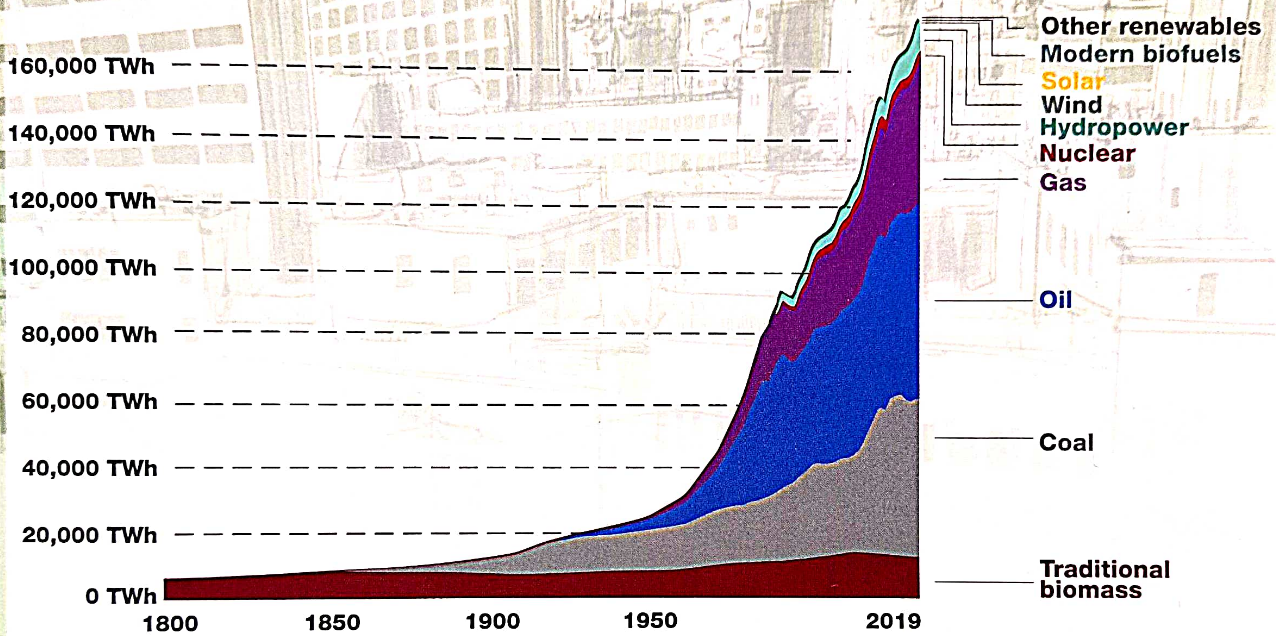
Volume 25 Number 3

May - June 2022

AIR CONDITIONING AND REFRIGERATION

Journal

The magazine of the Indian Society of Heating, Refrigerating and Air Conditioning Engineers



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Strategies for a Net Zero Energy College Campus

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ABSTRACT

This paper provides analysis and strategies for a net zero energy college campus and is based on green audits conducted in seven colleges in and around Mumbai over a three-year period from 2019 to 2021. Observations and analysis are limited to the information obtained from online data uploaded by these colleges and on-site surveys. The audited colleges varied in built-up area between 2,000 and 8,500 square meters and with Energy Performance Index (EPI) ranging from 7 to 54 kWh/m² per year. Strategies for net zero include a shift to energy-efficient equipment, lighting, fans and HVAC systems, improved day-lighting and solar rooftop with net metering. The combined total energy saving potential of these colleges exceeds 4,00,000 units of electricity annually with a total carbon reduction potential of more than 300 tons.

1. Introduction

Energy efficiency of buildings has become an important area over the last decade, given that buildings consume nearly 40% of the total electricity consumption. In new buildings, it is possible to include the efficiency of building envelope and systems, but addressing them in existing educational buildings is challenging and requires substantial alterations and investments.

At the COP 26 conference in Glasgow, where heads of nations met to deal with climate change issues in November 2021, India committed to a target of increasing its non-fossil energy to 500 GW and fulfilling 50% of its energy needs through renewable energy by 2030. It also committed to reducing one billion tons of the total projected carbon emissions between now and 2030, by which time it will reduce the carbon intensity of its economy by 45%. Finally, it committed to the target of net zero emissions by 2070. To achieve these, a multi-pronged approach is called for, which requires major sectors such as agriculture, industry and buildings to make fundamental changes to their energy usage policy and technology while anticipating and reducing emissions from growth.

Following the net zero commitments by India at the COP 26 in Glasgow, this study has relevance to the design and functioning of college buildings and provides strategies for a net zero energy college campus. The colleges audited varied in size between 2,000 and 8,500 square meters and with EPI ranging from 7 to 54 kWh/m² per year. The audited colleges have been referred to as C1 to C7 in this paper. Offering studies in various streams, mainly commerce and science and including hospitality management, communications and arts, the colleges are located in the suburbs of Mumbai and are representative of the large majority of colleges in the city.

School and college campuses provide a unique opportunity for net zero – be it energy, carbon, water or waste. With student population not exceeding a few thousands and built-up area largely below 10,000 square meters, they present a manageable project with maximum outreach potential as it involves the teacher and student communities. Most of the colleges are managed by public or private trusts. Based on their goals and vision, each campus has its own values to abide by. By and large, the trusts of the audited colleges are rendering a yeomen service to the society by providing quality education at reasonable cost to students in urban and peri-urban areas. Being administered by non-profit organizations, most colleges have modest buildings, which are naturally lit and ventilated with a few exceptions. Surrounding open space is a limitation in Mumbai and its surrounds, hence, spaces are multi-functional especially in colleges which are located in city centers.

2. Building Envelope and Spatial Layout

The college buildings surveyed had an average population including students, teachers, administrative and non-teaching staff of about 3,000, lowest being 110 and

Figure 1: Classrooms banked by corridors prevent heat gain necessitating less use of energy for thermal comfort

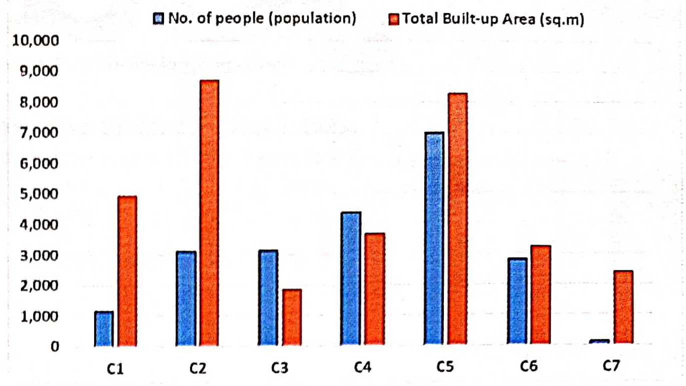

Figure 2: Population and built-up area shows an average of 0.7 persons per square meter

highest close to 7,000. An average space availability of 4.5 square meters per person was found, which is well within the standards.

The main aim in educational buildings is to promote a comfortable indoor environment with the maximum reduction of energy consumption. Many existing buildings have low energy consumption, but this is achieved at the cost of poor indoor environment, particularly with regards to thermal comfort. On the other hand, many existing buildings have good thermal and indoor environment but their energy consumption is high (Pavla, Brotas, & Mohelnikova, 2014). Almost all the colleges, with a single exception, had RCC framework construction more than 50 years old. A typical layout comprised of corridors doubly or singly banked with classrooms. Externally banked corridors were supported by parapet walls acting as verandah or balcony allowing for fresh air and ventilation. Staircases in most cases were adequate and large. Spill out spaces generally had no issues of ventilation. Only in C2, constructed a few years ago, there were no naturally ventilated corridors, mostly artificial light and fixed glazing on the external façade of the buildings. In general, the window-wall ratio was found to be around 20 to 50%, not directly exposed but through a shaded corridor except in C2, which had a glass facade.

Since the learning spaces in all colleges (except C2) were naturally ventilated, U-value of the building envelope was not significant, as external and internal temperatures were equalized through air flow. Therefore, with typical 230 mm brick wall on the external façade and 150 mm RCC slab with water proofing on the terrace, it can be estimated that the wall and roof had thermal transmittance (U-Value) of between 1.7 and 2.2 W/m^2K and 3.7 W/m^2K respectively. Glazing was uniformly single glazed with aluminum, timber and mild steel frames, the exception being C2, which had a large portion of curtain wall and tinted glazing.

3. Energy Consumption

Annual energy consumption varies from 17,000 units to 4.8 lakh units with an EPI range of 7 to 54 units per square meter per year. Energy consumption has been divided into four areas, viz., lighting, fans, AC and equipment. It can be

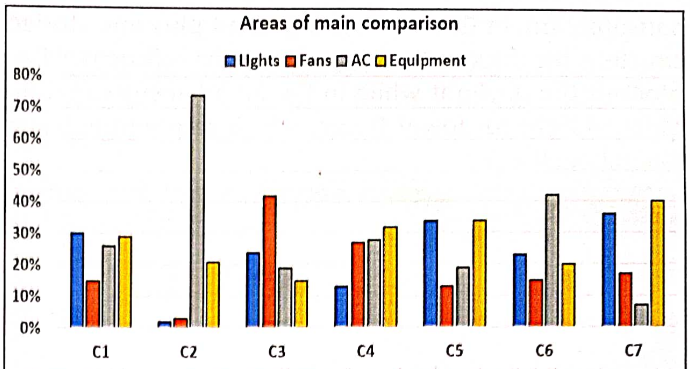

Figure 3: Energy consumption categorized under lighting, fans, AC and equipment in the 7 colleges surveyed

seen that even with minimal conditioned space, air conditioning occupied a bigger percentage share in most colleges. Two of the colleges – C4 and C5 – had rooftop solar with one of them, C4, catering up to 20% of energy consumption and a total load of 15kWp.

3.1 Lighting

The contribution of lighting to the total energy consumption was on average 23% but the variation was large, from 2% in C2, 13% in C4, 24 and 23% in C3 and C6, 30, 34 and 36% in C1, C5 and C7. The low percentage of lighting consumption in C2 and C4 was on account of switch to LED lights. In C1 and C7, the lack of natural lighting or enclosed corridors was the cause of increased percentage of lighting consumption. In C7, which is a ground plus one storied structure, the thick tree canopy outside the college building blocked the daylight while in C4, an adjacent structure blocked light for lower floors, which required lighting throughout the day.

Figure 4: Classrooms with daylighting and WWR of up to 50%

Most of the lighting fixtures in the colleges comprised of tube lights – 40 W and 36 W using electromagnetic ballast except in C2 and C7 where more than 90% lighting was LED lamps. Lighting levels and efficacy were also measured using the NBC standards for illumination levels and ECBC standards on Lighting Power Density (LPD). The former is a benchmark for visual comfort expressed in Lux and the latter provides efficiency standards in Lumens per watt. While illumination levels were found to be low in more than 50% of the spaces studied, LPD was found to be well within limits. Having adequate and well-designed daylighting can promote stimulating and pleasant learning spaces and students are required to be able to effortlessly undertake their tasks (Zinah & Coleridge, 2014). In C2, certain classes had no natural light whatsoever leading to continuous use of artificial light and poor lighting conditions.

3.2 Fans

Fans are the major active cooling mechanism in all colleges surveyed. Most fans consume between 60 W and 70 W at full speed. Energy consumption from fans ranged from 3,000 to 58,000 units across seven colleges. In C4, each classroom had a common switch for lights and fans for ease of switching off. In all other cases, energy waste from fans running in empty classrooms is common. Ceiling and exhaust fans in all colleges are major areas where energy efficiency can be achieved.

3.3 Air Conditioning

With the exception of two, the percentage of air-conditioned space did not exceed 12% of the area. All of them were unitary ACs – either window or split type. In two colleges, C2 and C7 the percentage of conditioned space was found to be 87% and 31% respectively. In C7, the increased percentage was on account of an auditorium, which was rarely used. In C5, AC connected load was high, however, the usage was low, implying underutilization.

Air-conditioning units were generally provided in the administrative areas, principal's cabin, computer labs and a few specialty labs. Almost all classrooms were naturally ventilated. Except for C2, which was 87% air conditioned (non-conditioned spaces were toilets and staircases), with a centralized unit and advanced VRV systems. In most colleges, up to 50% of the unitary air conditioners were star rated and well maintained.

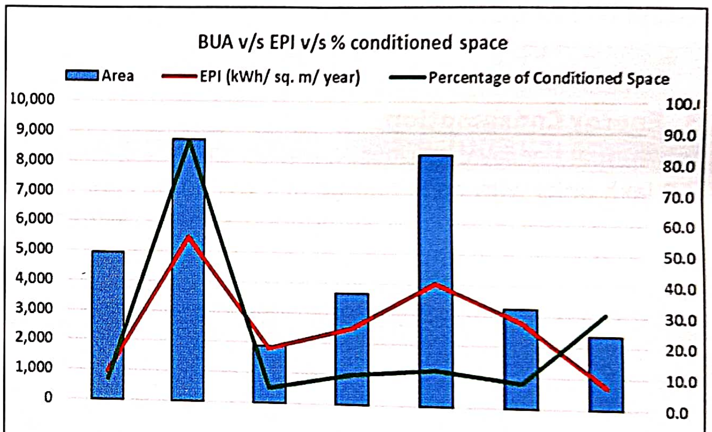

Figure 6: Comparison of built-up area (BUA), energy performance index (EPI) and percentage of conditioned space

3.4 Equipment

Computers, projectors, CCTV systems and pumps are the most common equipment used in all colleges. They contribute from 15% to 40% of the total energy consumption. College C5 had post-graduate courses, having some equipment in accordance with specialization in some fields of science. Most of the colleges have pumps with automatic switch-off mechanism, saving energy and water.

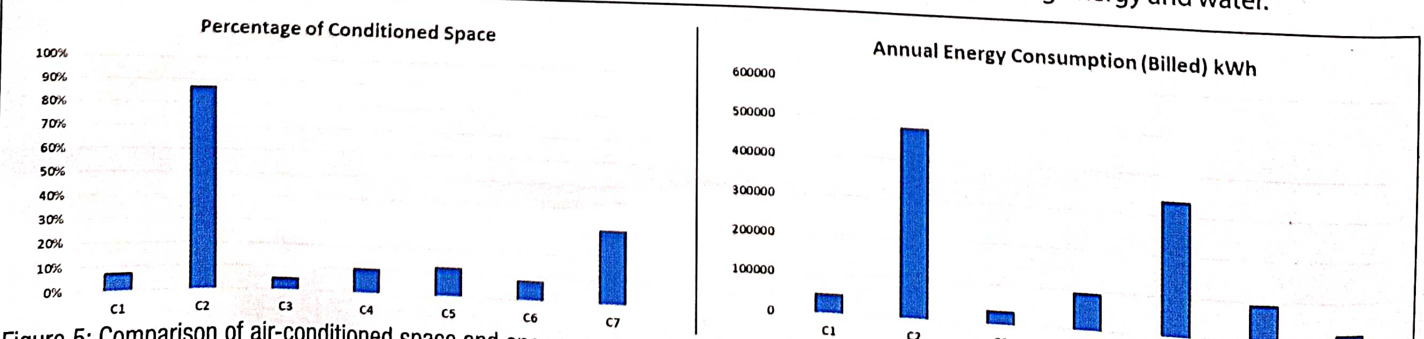

Figure 5: Comparison of air-conditioned space and energy consumed. In C5 and C7, while connected load of AC was high, usage was minimal

Table 1 : Overview of energy status of college

College	C1	C2	C3	C4	C5	C6	C7
Stream of education	Home Science	Commerce & Economics, Management Studies	Commerce and Art	Commerce & Management	Commerce Science and Arts	Commerce Science and Arts	Education
Population	1,153	3,106	3,144	4,365	6,950	2,833	115
Architectural character					Compact building planning	Well-lit classrooms and corridor	G+1 structure surrounded by vegetation
Wall-window ratio	41%	40%	50%	25%	25%	25%	20%
EPI (kWh/m²/year)	10	55	18	20	40	28	7
Conditioned space	7%	87%	5%	10%	12%	8%	31%
Potential energy saving (kWh)	42,288	90,975	66,491	18,916	66,096	66,852	41,825

4. Strategies for Net Zero and Energy Efficiency

Suggestions for changes in the building envelope included the use of high albedo paint or reflective coating application on the roof and walls, use of under-deck or over-deck insulation in the roof, introduction of light windows, light shelves and light wells to enhance daylighting and use of glazing with low solar and U factor in air-conditioned spaces.

Figure 7 : Rooftop solar PV in C4 provided 20% of electricity

In the active strategies, shifting from non-LED to LED lighting is the lowest hanging fruit for most colleges. It has low investments and high returns. Retrofits in the building envelope can help to improve daylight and natural ventilation, although investment is higher for this and it also requires checking the structural safety as most college buildings are more than 50 years old. Shifting to sensor-based dimmer lights in less occupied areas such as staircases and corridors that are lit throughout the night, the use of photo sensors and astronomical switches are some of the other suggestions for outdoor lighting and for spaces with substantial daylighting.

There is a large potential in shifting to energy efficient brushless DC fans, which consume nearly 50% of the energy consumed by existing fans. Under the demand-side management (DSM) scheme of electricity utilities, old fans could be exchanged with energy efficient ones at subsidized rates subject to specific policies and authorities.

Air conditioning units were largely unitary and in most of the colleges star-rated. Regular maintenance is the key to good performance. This goes beyond cleaning of filters and includes checking for gas pressure, compressor performance, insulation and several others. It is recommended that new equipment should be 3 or 5-star rated. In C2, energy efficient VRV system was installed for air conditioning. An automatic power factor controller relay (APFCR) panel (installed for maintaining power-factor to unity) was working satisfactorily. The voltage harmonics were well within the acceptable limits and only area of concern was presence of higher current harmonics. It was suggested to conduct a detailed analysis of current harmonics once the college re-opens post pandemic so as to draw clear conclusions and propose remedial actions.

Rooftop solar energy through net metering with electric utility company has an excellent potential for schools as most of the terraces are unutilized. In college C4, a 15kWp well-maintained solar rooftop plant catered to 20% of the college energy consumption. Initial capital investment was already paid back and the college was in the process of expanding this plant. In college C5 too, a 10 kWp rooftop solar plant was provided. However, it was neither well maintained nor connected with net metering, thereby, not accruing much benefits.

Specific improvements can also be achieved through introducing APFCR panel in case of power factor correction, earthing in case earth neutral voltage is beyond limits, change in wiring if overheated, separate metering and the use of IoT for energy management and monitoring.

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