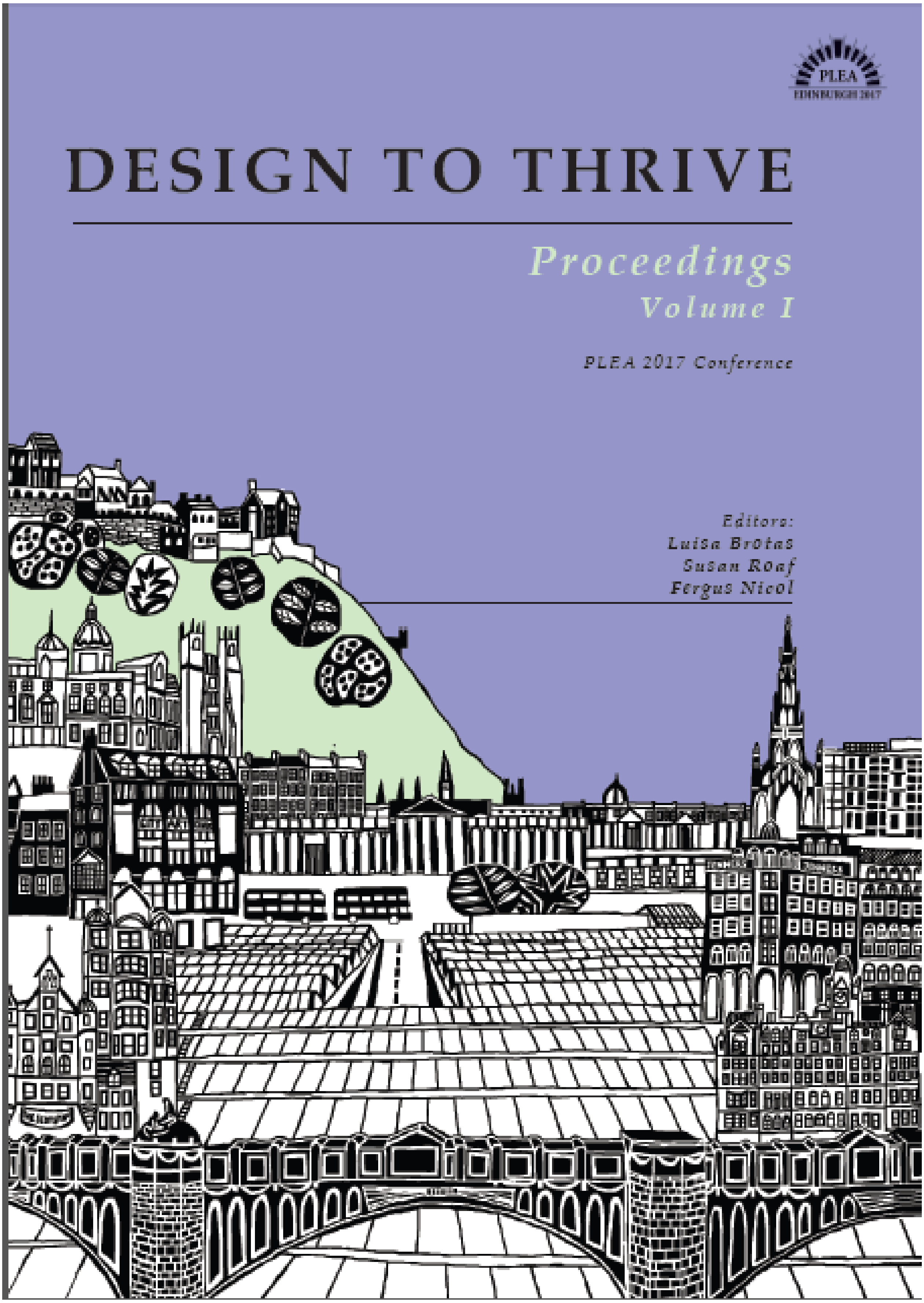

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Retrofit for Optimizing Building Thermal Performance in Warm-Humid Climate

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Abstract: In existing educational buildings, spatial layout over time is altered to meet functional requirements. However, these can adversely affect the thermal comfort of occupants. Spatial and structural retrofit can improve thermal performance of buildings. This research puts forth the results of a real-life retrofit project to improve building envelope and interiors for better thermal performance of an existing educational space in warm and humid climate of Mumbai. The aim of the research is to analyze the effect of retrofit measures on building thermal performance. Measurements of air temperature, relative humidity and surface temperature of the sloping roof–the largest exposed envelope surface - were undertaken pre and post-retrofit using appropriate instrumentation. Key factors analyzed include change in roof under-deck surface temperature, surface area to volume ratio, change in U-factor and Envelope Performance Factor of building elements pre and post-retrofit. Results show a significant drop in internal surface temperature of the roof post retrofit, which has a positive effect on the MRT and subsequently the operative temperature and thermal comfort of occupants. The retrofit measures used are economical and have potential for scaling-up across educational buildings in India, where low-cost solutions for thermal comfort and energy efficiency, are much required.

Keywords: thermal performance, retrofit, roof, envelope performance factor, warm humid climate, educational building

Introduction

As per the Central Regulatory Authority (CEA) 2013 Report, building sector in India accounts for 37% of total electricity consumption. Energy consumption due to space cooling and lighting has been found to account for one third of total energy consumption in residential buildings and two-thirds of total energy consumption in commercial buildings in India (Bhatt, Rajkumar, Jothibasu, Sudirkumar, Pandian, & Nair, 2005).

The building envelope acts as a mediator between the external environment and the occupants. It forms a significant element in total energy consumption and has a cascading effect on air conditioning and lighting. Hence, designing the building envelope for improved thermal performance is important for occupant comfort and energy consumption. Retrofit of existing buildings for energy efficiency can be costly and limited.

Retrofit Strategies for Improved Thermal Performance in Warm Humid Climate

Warm-humid climates pose a peculiar problem for thermal comfort of human beings. While the air temperature may be in the early 30s of degree Celsius, the high relative humidity results in great thermal discomfort. Retrofit strategies for warm-humid climate predominantly require increased air movement and reduced exposures to solar heat (Olgyay, 1963).

Indicators of Thermal Performance

Mean Radiant Temperature (MRT) is an important indicator of thermal comfort and performance. It is a measure of the average radiant temperature of surfaces within a space. It is suggested to maintain the MRT of a space below body/skin temperature (37^{0}C or 98.4^{0}F) to avoid net inflow of heat of the occupant's body through radiation heat transfer (Sehgal, 2010).

Surface temperature of walls and roofs are important indicators as they affect MRT and in turn the Operative temperature and thermal comfort. In this project, the roof area was 66.4% of total envelope area (excluding floor being on the sixth floor) and hence surface temperature of roof was considered an important indicator of thermal performance.

The Envelope Performance Factor (EPF), the trade-off value for the building envelope compliance option in ECBC 2007 has been used as an indicator as it considers the surface area of specific building envelope element, the U-factor or rate of heat transmission through the component, the Solar Heat Gain Component (SHGC) and a multiplier to account for shading of fenestrations.

Objective, scope and limitations

The main objective of the paper is to analyze the effect of retrofit measures for an existing naturally ventilated daytime space in a college building for thermal performance in warm-humid climate of Mumbai.

The heat-gain reducing and heat-loss promoting strategies are based on existing principles described above but also governed by limitations of budget, limitations of building byelaws and client requirements. The effect of the strategies is analyzed with respect to building thermal performance with focus on roof (being the largest surface area exposed to solar radiation)

Methodology

The study is located in the city of Mumbai, India, which is classified under warm-humid climate zone by the ECBC 2007. The research design is quantitative and includes measurements and calculations related to thermal performance of the building and its elements – pre and post-retrofit.

The retrofit project was undertaken in September 2012 and completed in March 2014. The project included retrofit design and layout, discussions with client (Director of the College) and users to meet their functional and spatial requirements and approval of budget, preparing tender documents, specifications and rate analysis for items not listed in the District Schedule of Rates (DSR).

Pre and post-retrofit analysis of design was based on calculations of surface-area to volume, U-value and EPF (Envelope Performance Factor), and measurements taken using Digital Hygro-thermometer, Electronic Infrared non-contact Thermometer, K-type (thermocouple) and RTD-PT-100 sensors and 8 channel data logger.

Analysis of existing building

The space under consideration admeasures 6938 sq. ft. (643 sq. m) located on the sixth (top-most) floor of one of three wings of a college building in South Mumbai. A post-independence construction, the design has a distinctive art-deco style reflected in the rounded columns, balconies and timber framed windows and doors. While the college management intended to renovate and redesign the sixth floor to meet its changing educational and spatial requirements, it also intended the renovation to address the problem of thermal discomfort of occupants.

Analysis of existing building envelope

The space is situated on top of 5 floors of the northern wing that is one of three rectangular blocks that comprise the C-shaped college campus building. The rectangular block is 33.3m in length and 19.2m wide. The longer axis is parallel to north and south. Both sides are flanked by a buffer space in the form of a long balcony corridor, which is 2.25m wide in the north shaded with a 0.6 m *chajja* and 1.65m *verandah* on the south fully shaded by a concrete shading device. The Window Wall Ratio (WWR) is 23.5 and 21.09% on south and north facades, and 14.79% on eastern façade. The western part of the block is connected to the rest of the building by a staircase and toilet block and passage.

The gable roof admeasuring 7296.639 sq. ft. (677.88 sq. m.) is made of asbestos cement sheets nailed to a steel truss that sits atop the brick walls along the building envelope. It includes translucent polycarbonate sheets provided for daylighting along the central corridor. The skylight-to-roof ratio (SRR) was 5.6% prior to retrofit.

It is a daytime use building as classes and offices close by 5pm. Proximity to Arabian Sea brings in cool winds from the northwest and west (prevailing and secondary wind direction for Mumbai). Peripheral walls are of brick masonry with cement plaster about 450 mm thick.

The existing building has ideal form (length to width ratio is 1:7) and orientation along east-west axis to reduce heat gain (Olgyay, 1963). Further, windows are provided with horizontal shading on north and south to reduce solar heat gain in summer and optimize day-lighting. WWR is also below 25% on north and south and 14% on East. The building is oriented to face sea breeze from NW-W. However, doubly banked corridors with two layers of classrooms, blocked wind movement and reduced window openings.

Analysis of existing building interiors

By way of volume, 19% of interior space prior to retrofit was enclosed within a false ceiling. A plywood false ceiling framework supported a Plaster of Paris (POP) false ceiling for all classroom and office spaces except the 18 m long central corridor.

The space comprised a mix of classrooms, offices, computer labs and HOD office separated by plywood partitions and 150 mm thick brick walls. The interior layout of classrooms rendered several windows un-openable. The spatial distribution of the space with two rooms placed one after the other between the external balcony corridor and the central inner corridor, provided little cross ventilation. Inner spaces were 'hot and suffocating' according to the occupants prior to retrofit.

Retrofit for improving thermal comfort – measures and materials

The retrofit design of the space included reorganizing the space to meet the new functional requirements of the college. The functional requirements of the space required a layout with classrooms for 80, 40 and 20 students respectively. Figures 1 - 3 provide a summary and photos of the retrofits on the 6th floor. Retrofit for thermal comfort was done by spatial and structural/ material measures which are summarized in Table 1.

Analysis of measurements and calculations pre and post-retrofit

The measurements were taken pre-retrofit (September 2012), at various stages of dismantling and construction (May 2013 and December 2014) and post-retrofit (May and October 2015). The Envelope Performance Factor (EPF) was calculated pre and post retrofit based on the formula provided in Appendix E of the ECBC 2011 (Bureau of Energy Efficiency and USAID ECO III Project, 2009).

Table 1: Retrofit measures and their purpose

Structural Retrofit		
S.No.	**Strategy**	**Purpose**
1	100 mm thick dry wall internal partitions supported by Galvanized Iron (GI) channels, and vertical studs at 600 mm centre to centre clad with a double layer of gypsum plasterboard screwed and taped, and filled in with glass wool insulation material - in place of 150 mm brick walls and plywood partitions.	For better heat and sound insulation, and faster construction.
2	High albedo paint having solar reflective index > 0.5 on asbestos cement roof sheet .	For reducing cooling load of buildings
3	Radiant Barrier under-deck insulation made of polyethylene air bubble film (ABF) laminated with aluminum foil on both sides underneath the AC sheet roofing suspended using a G.I Wire mesh with an air gap of 100mm. The composite thickness of the material is 4mm; its emissivity is in the range of 0.01-0.04 and its thermal transmittance is 0.07W/m2K.transfer	To reduce emission of radiation from roof surface. This is a radiant heat reflective low-e insulation material meant to effectively block the
4	Rotating head Roto Turbo ventilators – 12 nos. – of throat diameter 300mm introduced on the roof to facilitate stack ventilation in the classrooms. Made of aluminum with steel shaft, they are fixed onto the AC sheet of the roof. At wind speed of 6 km/hr, it is projected to have an exhaust capacity of 572cfm.	To induce stack effect and provide thermal comfort to occupants by means of induced convective ventilation
5	Translucent uniform flat polycarbonate sheets fixed on Mild Steel (MS) cleats provided onto existing MS roof truss at 200mm centre-to-centre gas welded to match the level of dry wall. A thin layer or EPDM flat strips or rubber flats are pasted on to the cleats or the MS flat along its inner side using, rubber adhesives and cured to dry	They provide acoustic insulation while allowing daylight penetration into classrooms.
6	19 nos. 1.5mm thick 1.0 x 2.0 m (effective opening) corrugated translucent AC profiled polycarbonate sheets were fixed onto AC sheets to provide day-lighting. The sheets are placed in a similar form and orientation to a regular AC sheet and lapped on the top and bottom by 150mm.	To provide adequate daylight in the classrooms
Spatial Retrofit		
S.No.	**Strategy**	**Purpose**
7	Increase size of classrooms and provide single row of classrooms in place of double rows on either side of the corridor	To enhance thermal comfort through cross
8	Removal of false ceiling	To allow for stack
9	Increase WWR by making all windows openable	To enhance cross

Results and Discussions

Effect of Solar Radiation on roof

Roof-bottom temperature surface temperatures post-retrofit lie below 32^{0}C (well below skin temperature) except along the ridge where the higher temperature can be attributed to the bitumen covered ridge sheet (Fig. 4).

Figure 1: Spatial layout before and after retrofit

Figure 2: Photo of Classrooms before and after retrofit

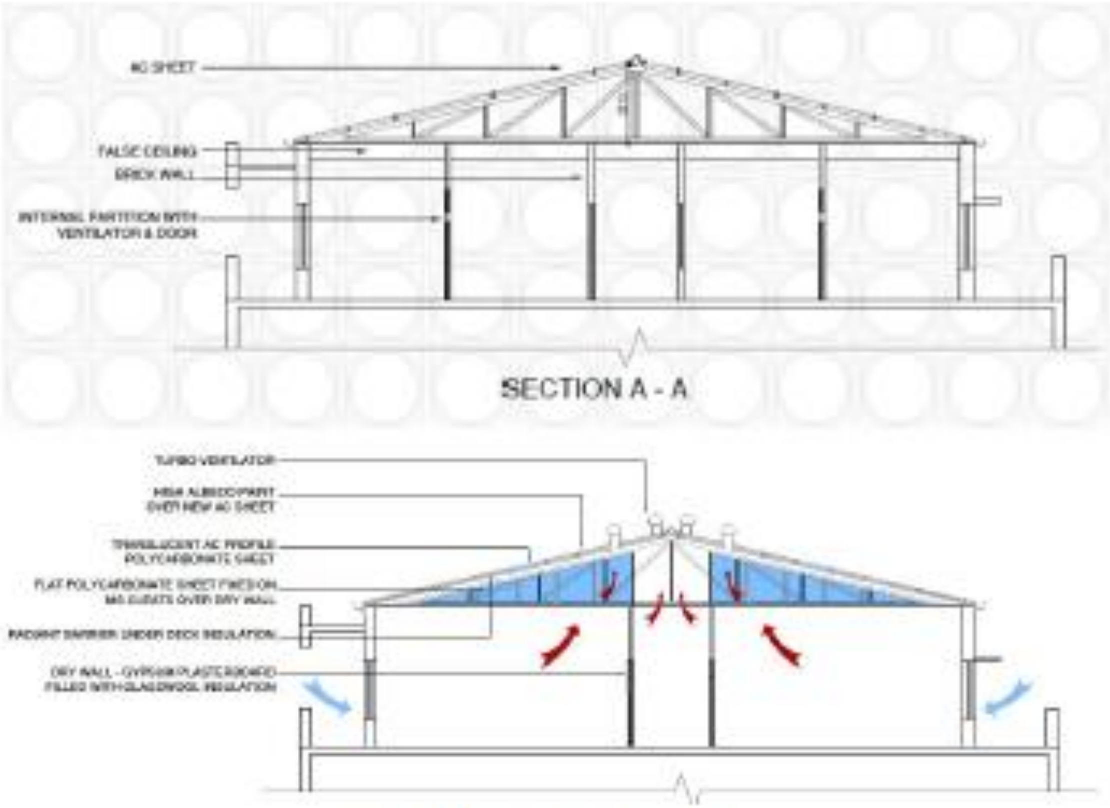

Figure 3: Pre and Post-retrofit section

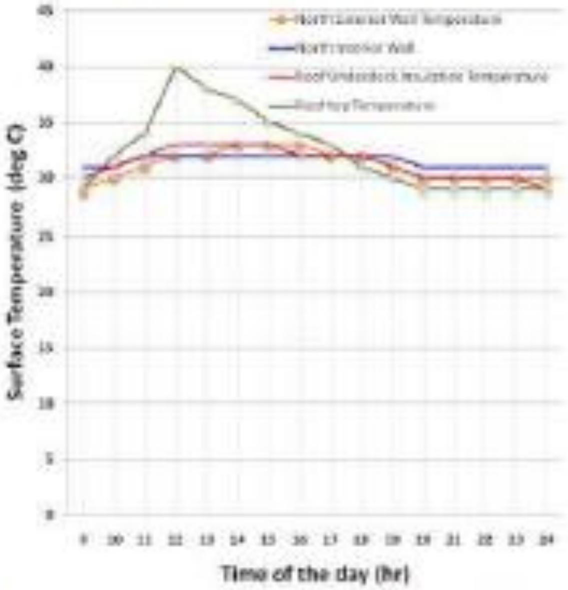

Figure 4: Roof bottom temperatures post retrofit are below 32°C

Analysis of retrofit measures based on calculations

Envelope Performance Factor

The retrofit has major impact on roof U-value (a measure of thermal transmittance of a building element such as wall, roof or opening) which reduced from 4.64 W/m2K to 0.07 W/m2K due to the use of under-deck radiant barrier with a low emissivity of 0.04% and thermal resistance of 13.7K m2/W along with 100mm air gap. The low emissivity of the radiant barrier material, which is a major surface area in each classroom, means low MRT and hence enhanced comfort conditions for occupants (Sehgal, 2010). Calculated Envelope Performance Factor (EPF) of the retrofitted roof is reduced by 98% and of the retrofitted space by 94% (Table 2).

Analysis of retrofit measures based on measurements of roof surface temperature:

Based on ambient air temperature and humidity data collected from the Indian Meteorological Department (IMD) pre and post-retrofit, the surface temperatures of roof under-deck were compared. The post retrofit temperature for similar climate factor shows a difference of about 10^{0}C (Fig. 5).

Table 2: Analysis of retrofit measures based on calculations

Building Component	**Property of Material** **Before RETROFIT**	**After RETROFIT**	**As per ECBC**
Roof U-value	4.64 W/m^{2}K	0.07 W/m^{2}K	≤0.409 W/m^{2}K
External Wall U-value	2.0 W/m^{2}K	2.0 W/m^{2}K	≤0.44 W/m^{2}K
Window U-value	7.1 W/m^{2}K	7.1 W/m^{2}K	≤3.3 W/m^{2}K
Roof SRR	5.6%	6.5%	≤5.0%
WWR (north)	24.98%	24.39%	≤60%(total)
WWR (south)	23.5%	23.17%	≤60%(total)
WWR (east)	14.79%	19.71%	≤60%(total)
SHGC (north)	0.72	0.72	≤0.25(total)
SHGC (south)	0.35	0.35	≤0.25(total)
SHGC (east)	0.82	0.82	≤0.25(total)
Note: No change in U-value of wall (2 W/m2K), window (7.1 W/m2K) and skylight (8.52 W/m2K); Doors and ventilators are considered in calculation for WWR (Window-Wall Ratio); SHGC is corrected to include effect of shading			

Conclusions and Future Work

In a developing nation such as India, where it is estimated that 66% of building stock is yet to be constructed, energy consumption due to space cooling and lighting has been found to account for two-thirds of total energy consumption in commercial buildings (Bhatt, Rajkumar, Jothibasu, Sudirkumar, Pandian, & Nair, 2005).

Educational buildings in India are, by and large, naturally ventilated and used during the daytime. Occupants mainly remain in a stationary position for periods of up to 45 minutes at a time either listening to lectures or performing some other activity such as drafting, drawing, laboratory experiments or even discussing. The study indicates that retrofit measures including roof insulation, and enhancement of stack and cross ventilation, can be achieved at a cost of less than Rs. 200/- per sq. ft. (GBP 2.5) with reduction in indoor surface temperature of roof of up to 100C in peak summer. Such cost-effective measures can be applied on a large scale in schools and college buildings to improve thermal comfort and reduce energy consumption.

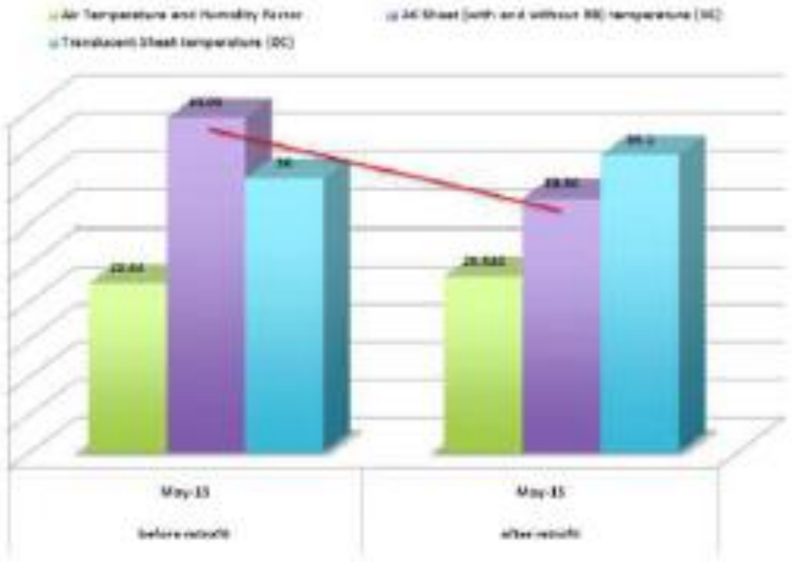

Figure 5: Analysis of retrofit measures – before and after retrofit shows nearly 10^{0}C post-retrofit

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