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Assessment of Passive Evaporative Cooling Measures on the IIT Gandhinagar Campus

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***Abstract*— The article presents a case study documenting and highlighting the effectiveness of passive cooling measures on the IIT Gandhinagar (IITGN) campus including passive downdraught evaporative cooling (PDEC), forced air evaporative cooling (FAEC), and dry night purge systems. The study reports representative data from about two months of testing in the summer months from both classrooms and the central student dining hall at IITGN. The impact of these systems on temperature and humidity is quantified and several observations about the utility, feasibility, and various executional and operational challenges along with practical experiences are highlighted. As reported in the study, the PDEC system appears to be a feasible and effective option to provide reasonable thermal comfort in large public spaces in hot and dry climates but much less feasible in confined spaces or when thermal comfort requirements are stringent.**

Keywords*— *Forced air evaporative cooling, passive downdraft evaporative cooling; thermal comfort.

I. INTRODUCTION

There is much interest and awareness about energy-efficient building ventilation systems on educational institute campuses. Yet, in spite of the huge emphasis on environmentally-friendly design of buildings and engineering services over the last several years, the adoption of new and unconventional ventilation systems on educational institution campuses have been slow. One obvious impediment is that these interventions usually demand permanent building-wide design modifications and specialized equipment and management. A less obvious but equally serious impediment is that there are few systematic studies and data of such systems on live campus environments in India. Systematic studies and documentation of such systems on an Indian campus will not only serve to provide validation of such technologies in Indian environment, but will also help highlight the no-technical challenges or considerations that are important for installation and commissioning of such systems on Institute campuses. Until these aspects are known, it thus becomes difficult for campus administrators to invest significant time, energy, and resources on such technologies.

In this article, we present a case study of passive cooling technologies installed on the IIT Gandhinagar (IITGN) campus, and report experimental observations while discussing key insights and experiences. The IITGN campus is situated along the river Sabarmati in Gandhinagar, GJ and was awarded a 5-star GRIHA LD rating in 2015, the first in the country to receive the 5-star rating in this category. The academic buildings under study in this article also won the first prize in HUDCO Design Awards 2016 in the Green Building category among other awards and recognition.

Passive building technologies are of two categories, one that focuses on preventing heat entry into interiors (heat-gain prevention) and the second on removing heat from the building (natural or passive cooling). We focus in this paper on passive cooling and specifically on passive downdraught evaporative cooling (PDEC), forced air evaporative cooling (FAEC) and night purge systems used in an operational academic environment at IITGN. The PDEC system works on the principle of evaporative cooling by introducing a fine mist into the hot and dry ambient air at a height above the space to be cooled, causing the air to cool due to evaporation of the mist and the latent heat of vaporization being extracted from the hot air. The cooled air being heavier sinks to the space that is required to be cooled thus displacing warmer air that exits from either vents or exhaust stacks. The FAEC system operates on similar principles but with an additional fan that helps increase the draught and thus providing potential for better evaporation, better mixing and improved cooling.

We present data and insights from the student dining hall at IITGN which is the main central mess on campus where all students on campus go for four meals a day, and from the main classroom complex at IITGN where all classes are held except the large first-year UG classes and few other larger classes (which are held in the larger learning theatres).

We share a few inferences and observations from the data and also recount practical challenges and hurdles that are equally important for effective commissioning and operation of the said systems.

II. BACKGROUND LITERATURE

Earlier studies [1]-[16] investigate (passive) direct evaporative cooling along with other methods like green-roofing, use of glazed tiles, night ventilation, green spaces, solar chimney and radiant cooling for cooling of the occupied areas by passive means, in constructed buildings for delivering

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thermal comfort to the occupants, while also discussing their utility, applicability and limitations. There are recent studies that focus on defining acceptable ranges of ambient conditions, classified by human subjects as comfortable and studies that attempt to classify Indian climatic conditions for determining suitability to passive cooling techniques. In a paper by Jindal [17], perception of thermal comfort by school students in a location with climate type Csa (hot-summer Mediterranean climate type typically with dry, hot summers and wet, mild winters) was studied to infer that neutral comfortable temperatures for the students were higher than what national or international standards would suggest for thermal comfort and that the students were comfortable with the variations in indoor temperatures. Furthermore, there are papers [18], [19] that discuss 21 regions in India classified for taking into account comfort, passive cooling and heating strategies and bio-climatic tools for analysing the effectiveness of such measures. Furthermore, there have been studies [20], [21] that suggest developing passive cooling measures for reducing the thermal discomfort time, instead of focusing on reducing temperatures. PDEC has been discussed with respect to the principles, construction and working in contemporary times by Ford [22], while giving an historical overview of the origin of these cooling practices, with a mention of Torrent Research Centre, Ahmedabad, the first facility implementing PDEC at a large scale. Use of a combination of multiple passive cooling schemes and their applicability based on different climatic regions in India have been suggested by Panchabikesan et. al [23]. Srivastav and Jones [24] argue that traditional dwellings in India were better suited for thermal comfort than the contemporary or modern architecture and have hinted at a possibility of confluence of both the approaches for a complete, energy efficient passive design. Typically, temperatures between 25 − 30 °C are perceived by occupants as comfortable [3].

III. CONTEXT: IITGN CAMPUS

The IITGN campus masterplan established environment-friendly design as one of its three core principles and had provided for a host of measures including campus-wide water treatment system, sewage-treatment and water recycling system, rainwater harvesting, solid-waste management and biogas plant, extensive use of solar energy, building envelope and roofing design for energy efficiency, passive ventilation systems, energy-efficient fixtures, etc. Due to these features and many other initiatives during and after constructions, IITGN campus was awarded a 5-star GRIHA LD rating and also won the first prize in HUDCO Design Awards 2016 in the Green Building category among several other awards and recognition.

IITGN campus is situated on the banks of the river Sabarmati near Gandhinagar, Gujarat (coordinates 23.2131 °North, 72.6870 °East), and has 'hot, semi-arid' climate of type BSh (Hot semi-arid climate type with little precipitation, mild to cold winters and hot to very hot summers) as per the Köppen-Geiger classification [24]-[26]. Weather in summer for this region comprises high to very high ambient temperatures (with maximum temperatures reaching above 45°C on occasion), low humidity and with almost no cloud cover.

The passive cooling measures discussed in this article (along with a multitude of other passive measures) are installed in the classroom complex in the academic buildings and student dining hall facility within the hostel complex at IIT Gandhinagar.:

A. Classroom Complex

The two-storied classroom complex (Academic Block 7) as part of the academic building complex has a total of 20 classrooms out of which classrooms numbered 103, 104, 105, 106 on the ground floor and classrooms numbered 204 and 205 on the first floor are included in this study. The entire classroom complex has a variety of passive low-energy cooling strategies with a different set of features installed in different sets of rooms to permit side-by-side comparisons with the intention to understand the effect of these technologies and aid subsequent decision-making. Some of the features include double-skinned envelope with cavity walls, night purge exhaust system, passive downdraft evaporative cooling (PDEC) system, forced air evaporative cooling (FAEC) systems, along with regular classrooms with no such features to act as a control group. In particular, classrooms 104, 105, 204 and 205 have the ability to operate in all three modes, night purge, PDEC and FAEC. As seen from the elevation of academic block 7 in Fig. 1, 104 and 105 are classrooms on the ground floor, 204 and 205 are classrooms on the first floor and all four of these classrooms are serviced by the same misting tower that is located between the classrooms and has openings into the classrooms. As seen in Fig. 2, these louvered mist inlets let the cooled air into the backside of the classrooms from the common misting towers. Classrooms 103 and 203 have no passive cooling features and serve as a baseline for comparisons. The misting tower generates mist by an arrangement of a pump (not visible) through misting nozzles distributed over a grid at the top of the misting tower. Each misting tower or downdraft shaft serves four classrooms. The amount of mist released from the nozzles is modulated by the pump pressure that can be varied from 250 to 1000 psi. A blower fan located at the top of the misting tower to force the mist downwards and into the classrooms can be turned on to activate the optional FAEC mode. When this fan is off, the system operates in the usual PDEC mode. Unevaporated water accumulating in the bottom of the misting tower is drained and recirculated. Vents and ventilators inside the classroom are set up so as to permit continuous inflow of cooled air from the mist tower and exhaust of classroom air to the outside.

B. Student Dining Hall Facility

A two-floor central mess/dining facility in the hostel complex caters to all hostels and students on campus (currently close to 2000 students during a regular offline semester) during meal-times. The plan view and the inside view of the facility showing passive cooling arrangements are shown in Fig. 3. These measures include a PDEC system with a downdraft tower running through the centre of the dining facility seating area on both floors and extending above the dining space from which ambient air enters. The exhaust shafts along the periphery walls allow the warm air to exit the dining area through return air vents. The downdraft tower has water misting at the top of the tower but does not have a blower and hence is a fully passive downdraft system. There are two key differences between the student dining facility and the classrooms from the perspective of passive cooling. First, the student dining facility is a substantially larger space with the ability to seat more than 300 students at any given time on each floor, while the classrooms are much smaller with a capacity of 40 students. Second, the misting tower is situated in the centre of the dining space with very few impediments to flow of the cool air along with liberal arrangement of exhaust stacks around the space. In contrast, the flow paths in the classroom are tighter with smaller openings and tighter turn angles. Furthermore, from a usage point of view, the student dining facility is a fairly public space with transitory occupation and constant influx and efflux of people. For an interested reader more details about these passive cooling measures are described in the institute's publications [27], [28], [29].

IV. PRINCIPLE OF OPERATION

In both PDEC and FAEC systems, the misting system is close to the highest point within the downdraft tower. When the fine mist released from the misting nozzles comes in contact with dry, warm air, the mist evaporates absorbing heat from the surrounding air to serve as the latent heat of evaporation thereby resulting in a drop in dry bulb temperature of the air, while increasing the humidity of the air. This cooler air being heavier drops downwards in the tower creating the passive downdraft. With appropriate design of vents in the downdraft tower directed towards the occupied space (ventilated space) and exhaust towers/vents in other parts of the occupied space for warm air to escape, a steady draught of incoming cooler air from the downdraft tower and exiting warmer air through the exhaust towers can be setup. The tall exhaust towers take advantage of the stack effect and thus further promote a stronger draught through the ventilated space. For FAEC, an additional fan at the top of the misting tower serves as a driving force to increase flow rate of the air. The amount of water entering the misting tower in the form of the mist is however not influenced by the fan and is controlled through the water pump. However, the efficiency of evaporation and increased flow rate due to the fan can enable a higher pump pressure and higher volume of water mist to be injected into the misting tower. Both these evaporative systems work best in warm/hot and dry conditions (which is typically April-June at Gandhinagar).

Principles of cooling by night ventilation or dry night purge are outlined in literature [25], [26] and are particularly useful when the ambient temperature during the night is low. Night purge is effective in reducing cooling costs by removal of heat stored/trapped in the walls (thermal inertia), thereby creating a delay until the walls heat up during daytime. In this mode, the blower fan essentially operates in reverse (with the misting tower turned off) so that air is pulled out from the classrooms and exhausted through the mist tower allowing cooler ambient air to enter the classrooms through the vents and thereby cool the space.

The resulting air temperature drop in any of these systems depends on factors like initial temperature and humidity of the warm air, residence time of air and mist, and the amount of mist in the misting tower.

V. EXPERIMENTS AND OBSERVATION

A. *Instruments and Experimental Setup*

a) For recording the temperature and humidity information, an 'HTC easy Log' temperature and humidity data-logger is used. The use of such a data logger is also reported in Pellergino et. al [20]. The data loggers provide temperature measurements in the range of −40° to 70°C, with an accuracy of ±1°C within the range of −40°C to 40°C and full-range humidity measurement with accuracy of ±3% within the range of 35% RH to 80% RH and ±5% otherwise. The resolution is 0.1% for humidity and 0.1°C for temperature. A total of nine such data-loggers were used. The data-loggers are factory calibrated and have no provision for calibration by the user. Hence, these were compared with a laboratory calibrated thermocouple having an accuracy of ±0.5°C, to account for span-zero deviations. The measurement rate was chosen as one sample of temperature and humidity measurement per 60 seconds.

B. *Classroom Complex Experiments*

For measuring the temperature and humidity conditions in the classrooms, the data loggers were placed in the centre of the respective classrooms. Measurements of ambient temperature and humidity are recorded (from a suitably shaded location outside the building) to draw comparisons with the measurements inside rooms with passive cooling. Additionally, temperature and humidity measurements in classroom 103 are used as a baseline to control for thermal effects due to the architecture in the classroom complex and other passive measures like glazing, shading, roofing, etc. Recall that classrooms 103 and 203 are not provided with a PDEC system. Usage of ceiling fans within the classrooms and regular occupancy was permitted during the experiment period thus possibly disrupting flow patterns and draughts within the classrooms (but no disruption inside the misting tower). The occupancy however remained low and intermittent due to summer months.

Results

A number of tests and measurements were conducted during the period of May-Jun 2016, of which we present here representative data from May 30-31, 2016 represented in Fig. 4. The trends for the rest of the testing period were also similar. In the tests depicted in this Fig., dry night purge is switched on starting at 2200 hours at night until 0500 hours next morning to bring classroom temperature and humidity close to the ambient conditions. Later, the PDEC system is started with misting at a pressure of 1000 psi from 0500 hours in the morning so as to pre-empt the effect of incident sunlight and subsequent rise in temperature. The PDEC system remains on until 1700 hours in the evening. From Fig. 4, it is observed that a couple of hours after the misting is commenced the temperature drops in Room 104 by almost 5°C as compared to the baseline to about 27°C with a corresponding significant increase in the humidity. The transient indicating cooling of the rooms (room 104 prominently) is seen just after 0500 hours in both temperature and humidity graphs. Warming effects of the incident sunlight (ramping up and irregular temperature and humidity changes) are seen after 0800 hours in the morning. The temperature in

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classroom 104 on the ground floor between 1600 hours to 1700 hours is about 10°C lower than ambient and at least 6°C lower than the baseline (room 103). In contrast, the same PDEC system while operational in room 204 on the first floor seems to not be as effective, hardly resulting in a temperature drop of a degree or two with a correspondingly small impact on the humidity in the room. Likewise, the net effect of dry night purge appears to be less than a 1.5°C temperature drop (as seen at 0500 hours).

C. Student Dining Facility Experiment

The temperature and humidity data loggers were placed at several representative locations within the main dining area of the student dining hall on both the floors taking into account the occupancy. Unlike the classroom complex where thermal comfort is required for the entire day, the requirement of thermal comfort in the dining facility is only for a few hours during meal times. Lunch time between 1200 to 1430 hours was observed to be the warmest period as a consequence of both ambient conditions, kitchen usage, and occupancy. Hence the tests were conducted around lunchtime. Furthermore, unlike the classroom complex wherein room 103 was used as a baseline, there was no possibility to set aside a portion of the student dining facility as baseline. To address this issue, during the testing period, the passive cooling system was operated in 'ON' condition on alternate days and 'OFF' condition on the other alternate days to enable comparison between the 'ON' days and the 'OFF' days.

Results

A number of tests and measurements were conducted during the period of May-Jun 2016, here we present representative data from June 13-14, 2016 in Fig. 5 with the misting system being switched 'ON' on 13th and 'OFF' on the 14th. The trends for the rest of the testing period were similar. The PDEC system is started before 1200 hours to pre-empt temperature rise due to occupancy at lunch time. The resulting temperature and humidity plots for both the first and the ground floor of the mess/dining facility are shown in Fig. 5. The temperature in the ground floor was close to 30°C and stayed within the band of 30°C to 32°C for the entire period and across all locations. On average, the temperature on the 'ON' day was about 4°C cooler than an 'OFF' day with ambient temperatures remaining about the same on both days. Similar to the classroom complex, as compared to the ground floor, the first floor shows a much smaller effect of the passive cooling systems with temperature drop between 'ON' and 'OFF' days being about 1°C.

Upon further observation of the issue of lower efficacy on the first floor, it was realized that balancing of the airflows between the two floors in the classroom complex was not appropriately planned and it was difficult to amend this without serious infrastructural interventions owing to the more complex flow paths and sharper turns in the flow paths. On the other hand, in the student dining hall, not only is it easier to change the angles of the louvres, it was also realized that a set of cross baffles that were initially proposed by the design consultants were 'left out' during the constructions. Upon subsequent installation of the cross baffles, the temperatures for the two floors in the student dining hall show much closer match as seen in data recorded using the same instruments and similar arrangement in April 2018 in Fig. 6 (time plots and box plots).

VI. DISCUSSION

On the whole, passive cooling systems proved to be effective and meeting expectations when the ambient conditions are hot and dry (typically three months in a year at IITGN). However, there are a number of factors worth noting here that became apparent to us upon adoption and daily usage of these systems.

The student dining facility being a large (approximately 500sqm area per hall) and public space with transient usage (a typical user spends 20-30 minutes in the facility per meal) and a relatively simplistic design, the cooling provided by the PDEC system was found satisfactory by most users. The almost 4°C drop in temperature is readily perceivable by the users particularly when observing the difference between 'ON' days and 'OFF' days.

In contrast, in the classroom complex, the space is more confined (approximately 62sqm area per classroom), students spend longer periods of time (1hr to 2 hrs) in the same classroom, and have higher expectations of thermal comfort. In addition, projection systems, monitors, computers, and other audio-visual systems installed in the classrooms are more sensitive to temperature and particularly to humidity. As a result, users were generally much less satisfied (as ascertained from informal surveys) and often complained of high humidity and wetness, and high noise levels from the FAEC fan. The manufacturers and maintenance crew of the electronic equipment in the classrooms also frequently complained about very high humidity, condensation and wetness in the classrooms (accompanied by warnings of danger to the equipment if the high humidity persisted for extended periods of time). While the humidity levels can be controlled by adjusting the misting pump pressure, frequent fluctuations in ambient relative humidity meant that the misting pressure had to be readjusted sometimes on a daily basis. A spike in ambient relative humidity that was not met with a corresponding lowering of misting pressure would cause very high relative humidity levels within the classrooms with condensation on various surfaces and sometimes even waterlogging in some parts of the classroom. Such situations were frequently encountered especially in June with the approach of monsoon. Due to these challenges, the passive cooling systems in the classroom complex were subsequently decommissioned in favour of regular air conditioning to meet the more stringent requirements of the formal setting. The PDEC in the student dining hall however continues to be successful even now owing to the nature of the space, usage and the relatively simpler design. The system in the student dining hall was also observed to be less sensitive to fluctuations in ambient conditions.

When the second phase of hostel constructions were undertaken, the use of some combination of passive cooling systems for the hostel rooms were again considered at length with a large number of consultations and discussions. Owing to the challenges similar to the ones mentioned in the classroom complex, the idea of using a passive cooling system was dropped for the rooms in favour of a night-only central air conditioning system that takes advantage of additional capacity in the central chilled water plant owing to reduced load in the academic area at night. However, for the dining halls of the new hostel a PDEC system similar to the student dining hall is planned and is under execution in the second phase of construction.

In addition to the considerations highlighted above, a number of practical challenges including constructional and administrative challenges were also encountered that are highlighted below.

A. Other Practical Challenges

Given that the passive cooling systems were not common or standard features found in other buildings, were customized designs, and were a very small part of the large construction activities, the construction agencies and contractors sometimes found it difficult to dedicate enough attention to understand the nuances in the installation of passive cooling systems. As a result, there were a large number of deficiencies in the systems, some of which had to be rectified later and some of which could not be corrected. For instance, the 'missing out' of installation of baffles in the student dining facility is one such example of an error that could be fixed later (although it took more than a year to rectify this post construction). Similarly, many louvres were installed with incorrect angles and directions, several openings were incorrectly provided. The internal surfaces of the misting shafts were also not appropriately finished to meet the high humidity requirements. Some of these surfaces had to be subsequently tiled to avoid the possibility of mould growth. The misting tower (for classroom complex) had openings from outside originally intended for wind/breeze to enter the tower and assist the mist into classrooms. These however frequently caused the mist to escape outside the tower instead of entering the classrooms and were subsequently plugged. The location and orientation of misting nozzles were ambiguous in the drawings and had to be iterated a couple of times on site.

There were more serious errors as well. The height and geometry of the misting shaft in the classroom complex was incorrectly executed thus rendering a permanent handicap. The fan chosen by the consultant for the FAEC was a noisy industrial fan not suitable for use in a classroom environment. This aspect required extensive coordination to explore methods to minimize noise post installation and finally a VFD system was installed to simply reduce the fan speed to partially minimize the noise.

The maintenance and regular cleaning of the nozzles requires attention of the maintenance team but is not a significant challenge.

B. Recommendations

Based on the above analysis and experience, we feel confident in suggesting that the PDEC can be a feasible option and effective in use in large public spaces in hot and dry climates (and only during the periods when it is hot and dry). It has the potential to provide reasonable thermal comfort and at negligible energy consumption thus proving to be a very attractive option particularly when energy consumption is an important concern. It will however, need a reliable source of soft water as water with high TDS levels can cause the nozzles to clog over a period of time. However, PDEC seems to be much less suitable in smaller enclosed spaces. The design and construction of the various civil and infrastructural elements related to the PDEC systems will also need careful monitoring to avoid challenges later on. The above recommendations are also supported by IITGN's decision to continue with the PDEC system in the student dining halls in the next set of constructions that are currently underway while choosing to not adopt passive systems in classrooms or hostel rooms.

VII. CONCLUDING REMARKS

The article presented a case study documenting and highlighting the effectiveness of passive cooling measures on the IIT Gandhinagar campus including passive downdraught evaporative cooling (PDEC), forced air evaporative cooling (FAEC), and dry night purge systems. The study reported data from both classrooms and the central student dining hall. The results indicate a significant 4-5 °C drop in the temperatures of the dining halls and classrooms providing thermal comfort to the occupants. However, a disparity between cooling efficiency on the ground floor versus first floor with the first floor cooling being not so effective was observed. Further balancing helped mitigate this disparity in the student dining hall but could not remedy the issue in the classroom complex. Due to other associated issues in the classroom complex (high humidity, wetness, noise, fluctuation of conditions), the passive cooling systems were subsequently decommissioned in favour of regular air conditioning to meet the more stringent requirements of the formal setting. The PDEC system in the student dining hall however continues to be operated effectively. A number of other considerations, practical experiences and challenges were also highlighted for the benefit of others who might consider adopting such systems. In closing, the PDEC system appears to be a feasible and effective system to provide reasonable thermal comfort in large public spaces in hot and dry climates but much less feasible in confined spaces or when thermal comfort requirements are stringent.

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Finally, the students and users of these facilities require special mention for cooperating with frequent testing and

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change of settings and indoor conditions during the experiments.

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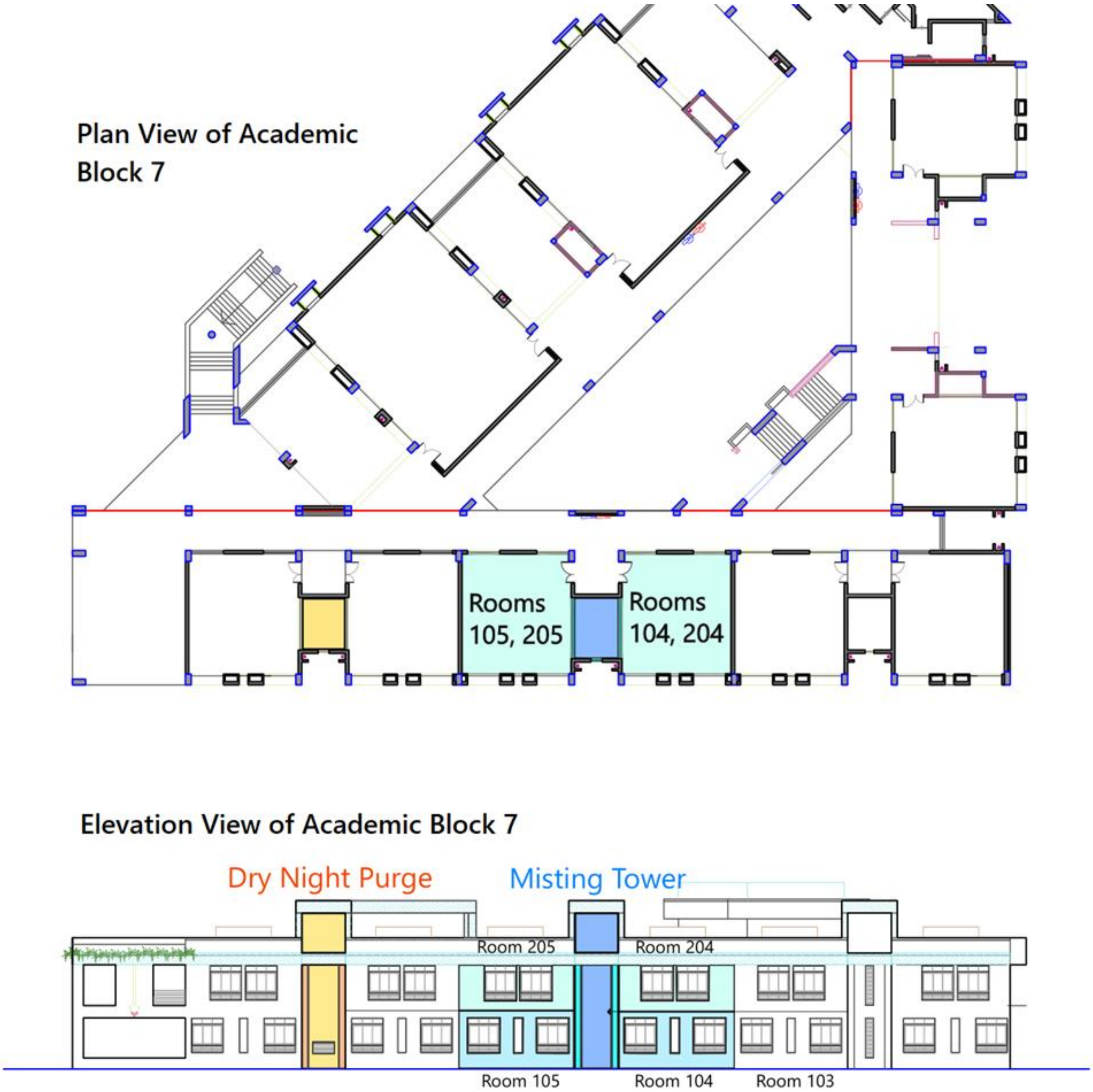

Fig. 1 Classroom Complex: Plan and elevation views showing the arrangement of classrooms under study and misting tower (Images adapted from architectural CAD drawings).

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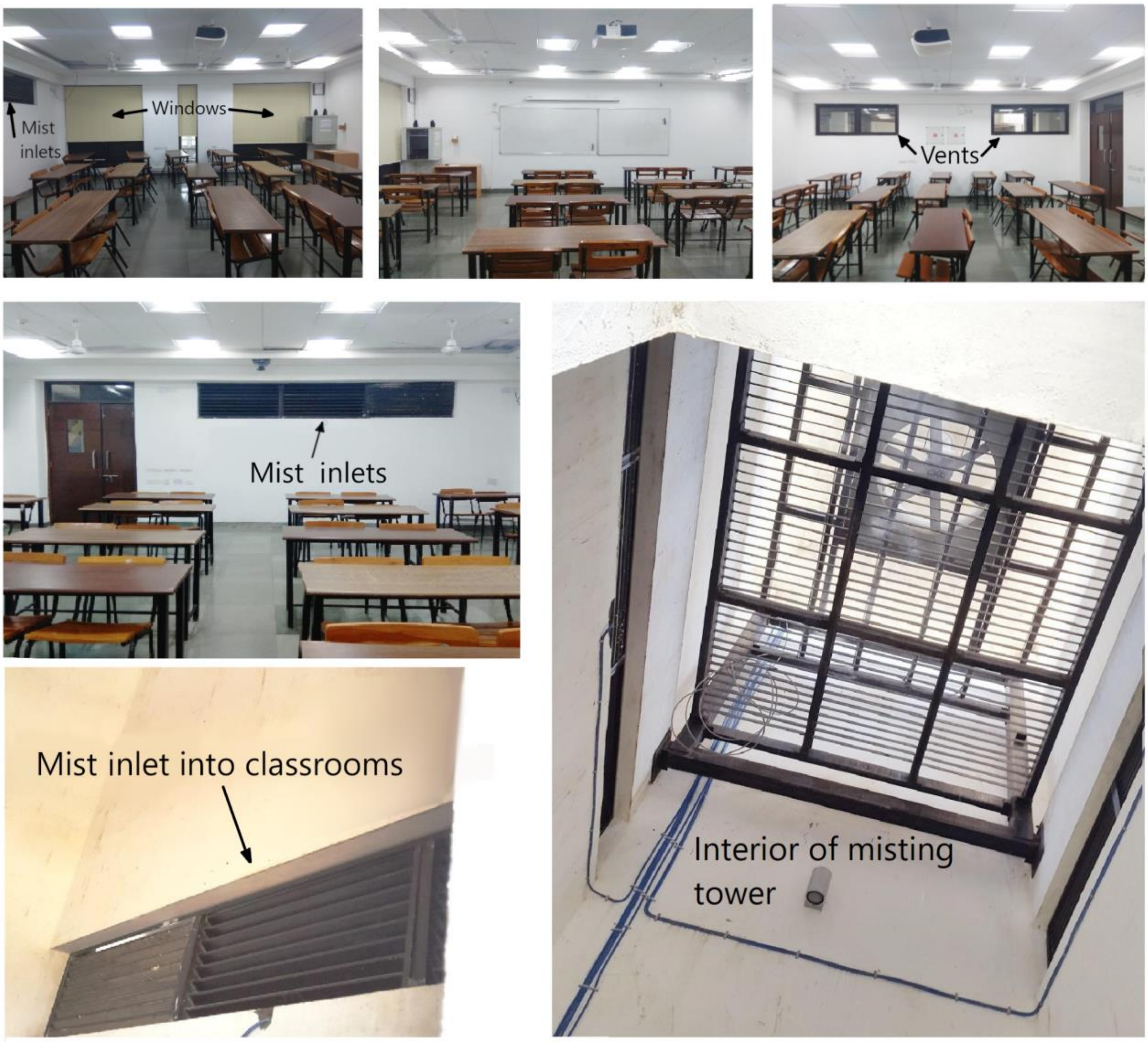

Fig. 2 A typical classroom and misting tower in the classroom complex highlighting the arrangement of various inlets and vents.

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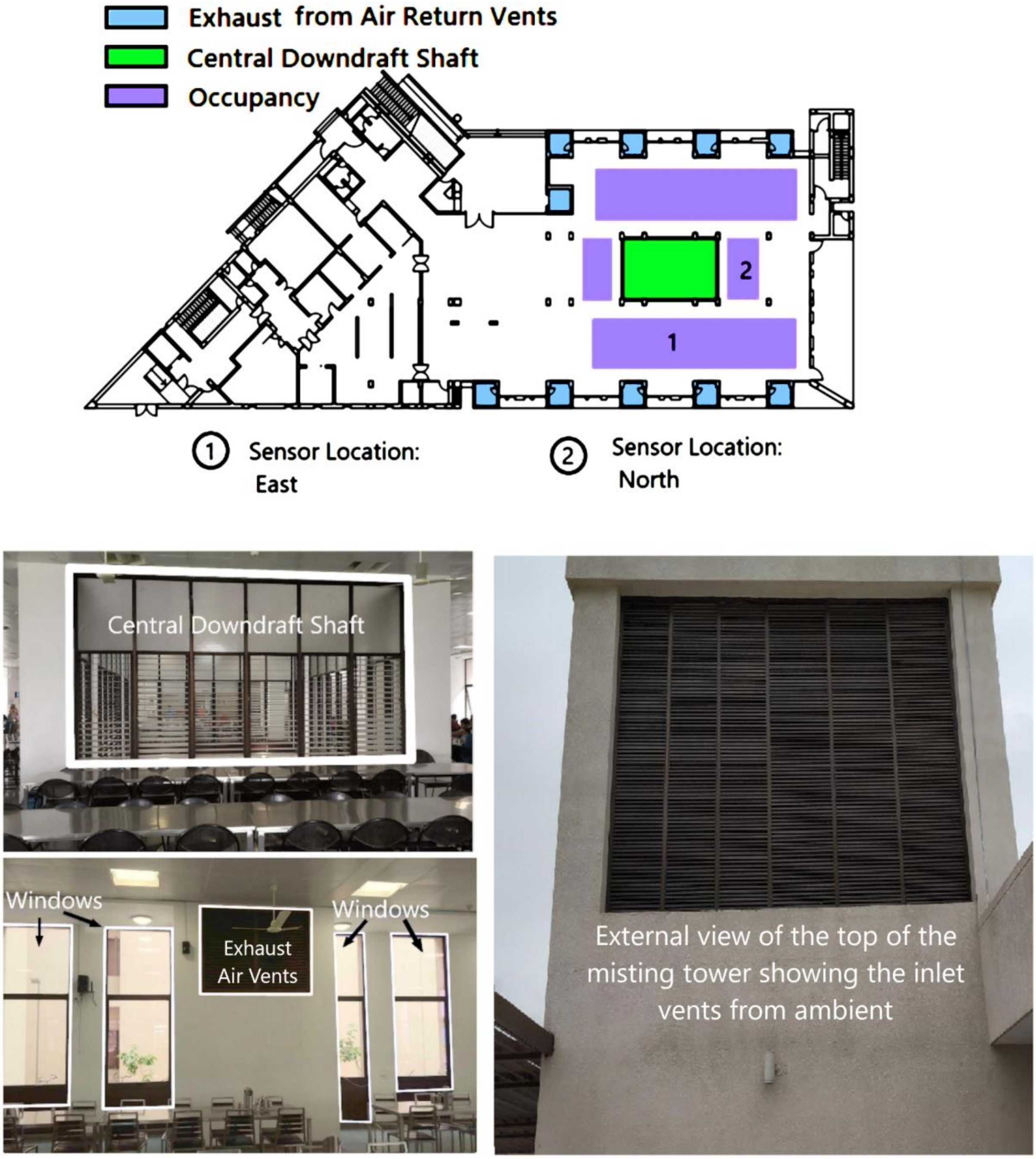

Fig. 3 . Student dining facility: CAD drawing showing plan view of the dining facility and views from inside and outside showing downdraft shaft and exhaust vents (CAD drawing adapted from architectural drawings).

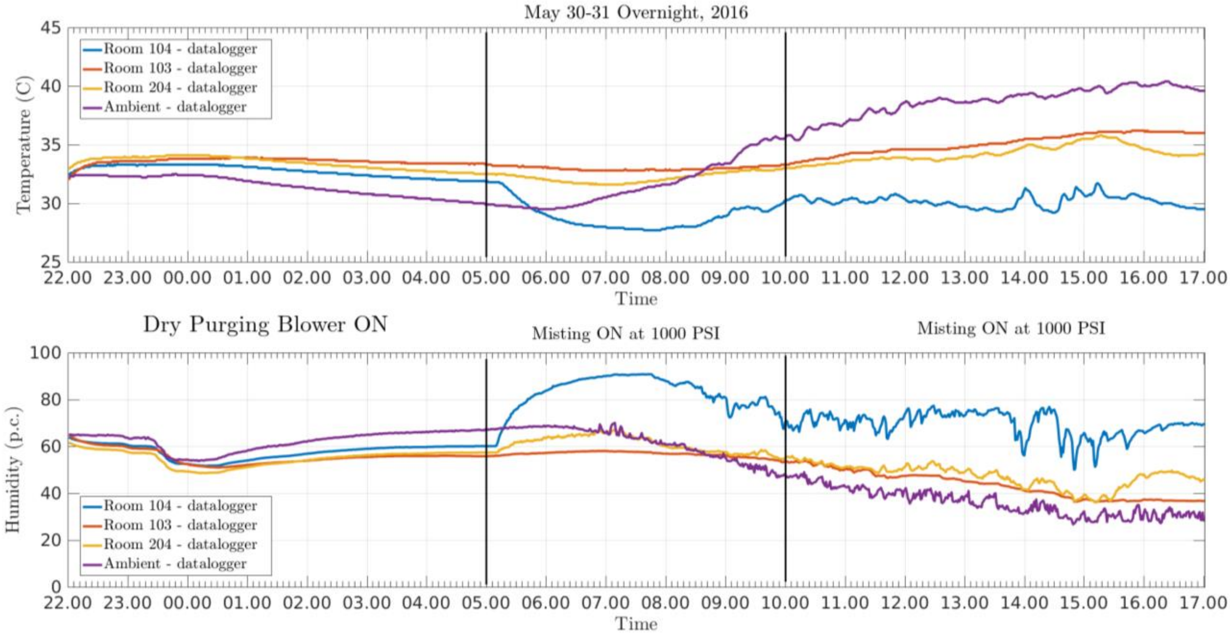

Fig. 4 Classroom complex: Experimental test over an entire day of dry night purging and forced air evaporative cooling.

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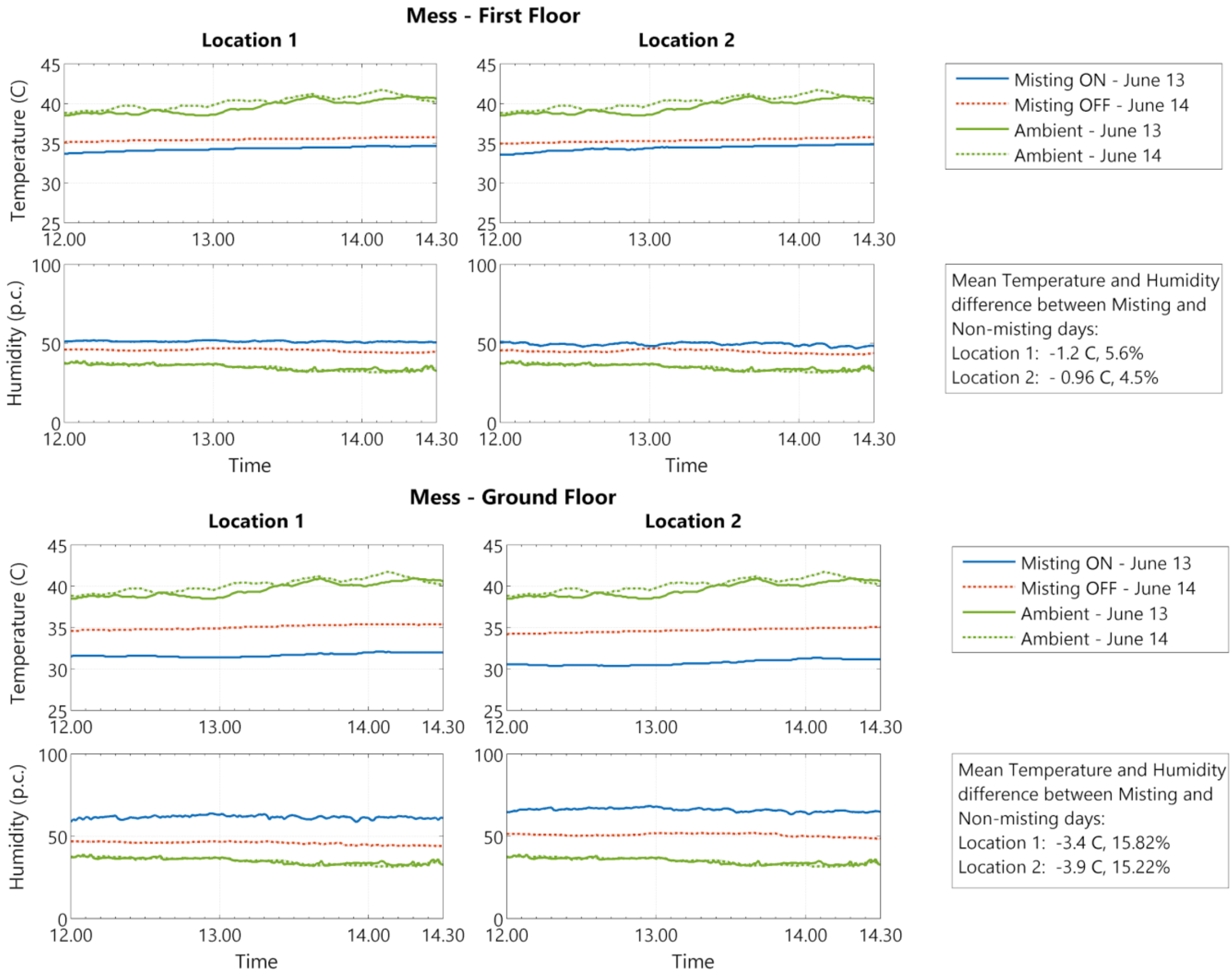

Fig. 5 Student Dining Facility: Experimental tests over two days of the passive downdraught evaporative cooling system.

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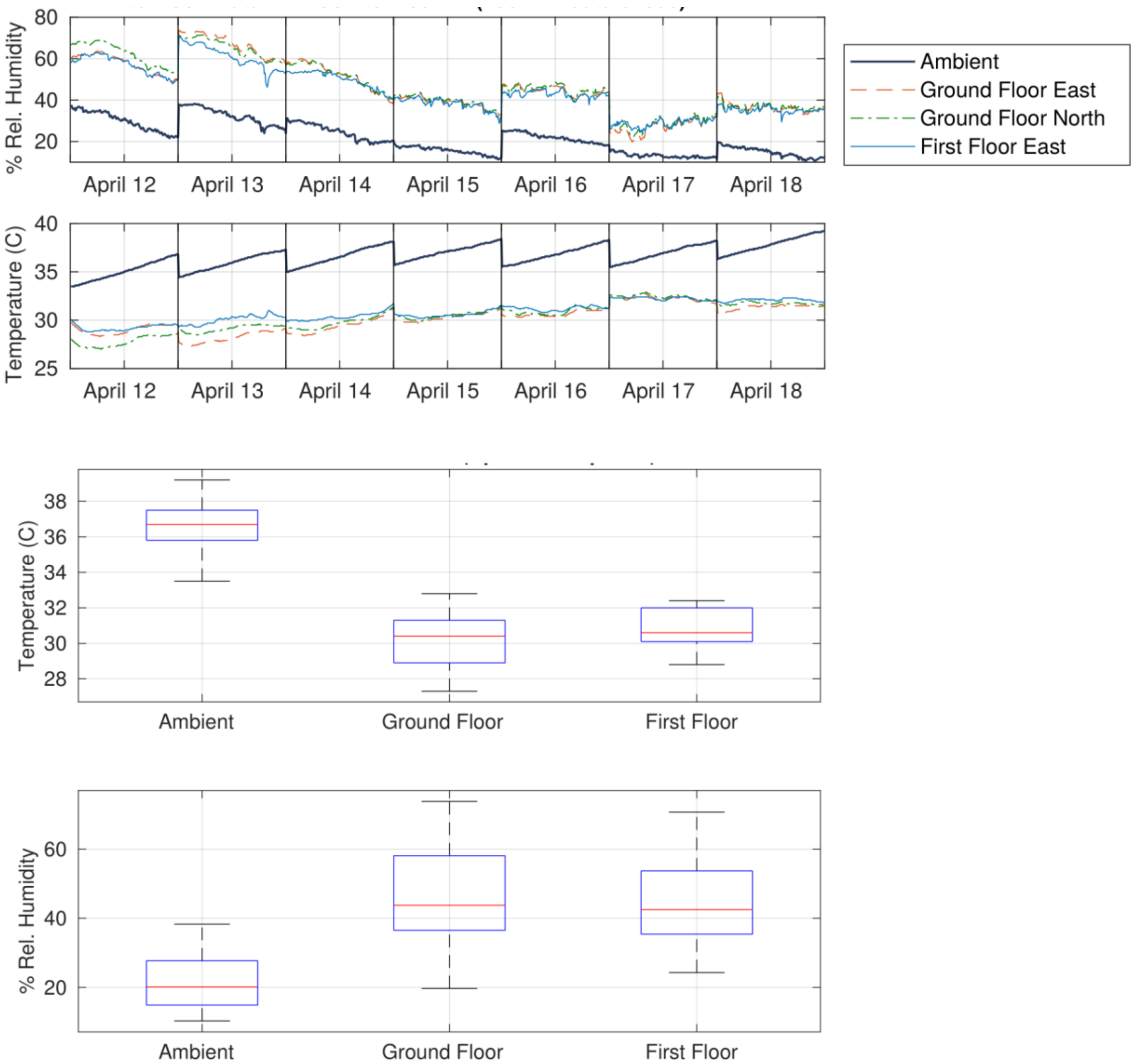

Fig. 6 . Student Dining Facility: Data collected in 2018 after installation of cross baffles and balancing of airflows between the two floors.