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Post-disaster reconstruction: Thermal and Visual Comfort analysis of reconstructed school buildings after Gorkha Earthquake 2015 (Case of type design of Lalitpur district)

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Abstract

Several school buildings were rebuilt which were destructed by the massive earthquake followed by in-numerous aftershocks of April 2015. The school buildings i.e. type design has mushroomed considering earthquake resistance design. However, the study on its indoor thermal and visual environmental is still lacking. The purpose of this research is to study thermal comfort and visual comfort of the type design constructed at the Lalitpur district using a simulation tool whereas a field study based on survey questionnaires with secondary students and teachers is used to validate the simulated data. The study was carried out in 9 naturally ventilated classrooms of four different schools during the winter season. Besides collecting energy consumption data and environmental data, a self-reported questionnaire and an observation form were employed to record children's thermal comfort and visual comfort. From four schools, 154 students aged 11-16 and 9 teachers were surveyed and questionnaires were collected. A methodology is based on a holistic approach that correlates students' post-occupancy evaluation with software simulations. Different scenarios of school buildings under natural ventilation were created for simulation where Case A is base case scenario whereas other scenarios are created making changes in building orientation, building envelope, glazing materials and openings which showed Base Case has discomfort hours and problem in daylight which is then corrected in Case C by introducing optimal passive parameters which showed a decrease in discomfort hours and sufficient daylight. The result confirms that the proper design consideration and suitable building materials aids to improve both thermal and visual comfort in the school buildings.

Keywords

Post disaster Reconstruction, Type design, School Building, Classrooms, Thermal Comfort, Visual Comfort

1. Introduction

Nepal was hit hard by a massive earthquake of 7.8 Mw on April 25, 2015, greatest earthquake of Nepalese record after 1934 which was followed by in-numerous aftershocks which destroyed several buildings including 8,242 public schools endangering lives of students and academic staff and disrupting their education [1]. For reconstruction of school buildings for thousands of affected students, models of buildings with well-defined construction details, termed as type design for schools are put forward by government of Nepal and several development partners addressing both short term and long term reconstruction, along with the overall agenda of build back better. By now the reconstruction of 4,476 schools has been completed so far and 1,772 are under construction using this guidelines.

In present world, people spend over 90% of their time indoors, hence creating optimal indoor environment has become of prime importance. Students spend most of their time at school beside their home highlights the importance of providing comfortable indoor environment in school building.The relationship between indoor environmental conditions and student achievement is known but creating a good indoor environment is rarely taken into consideration. According to [2] it was observed that the main reason behind absentia is mainly due to cold in the class rooms, while the teachers used layers of warm clothes to protect themselves from cold and to attend the school the students stayed in their homes as they were hardly able to afford the warm clothes Children attend schools for a long period and good indoor comfort conditions must be guaranteed with reduced energy uses. In the past century, school facilities have improved in some ways. But in other ways, especially in the skills and knowledge of natural lighting and thermal conditioning, we may have just hovered back to where we began.

Natural disasters are devastating to communities and homes, yet they can also offer an opportunity to integrate energy-efficient and disaster-resilient technologies and materials during the reconstruction process but at the same time the recovery condition can present exceptional and maybe new degrees of complexity in decision making compared to normal planning and development. The built school buildings have served the space satisfaction for students however those structures are extremely agreeable enough for them is to be considered. As a matter of fact the study of indoor environment after post occupancy is one of the major factor in order to state reconstructed school buildings as student friendly building since the presence and performance of students and staffs depends on the indoor environment quality.

One way to ensure that we move towards a design paradigm that emphasizes reflection and honest feedback loops is to implement more rigorous standards of practice in school design and operation that are based on performance measurement of buildings and post-occupancy evaluation. Hence, the paper investigates on thermal and visual comfort under natural ventilation of the four school building reconstructed at Lalitpur district.

2. Objectives

So as to improve the circumstance and considering the significance of indoor environment quality in influencing the students' learning procedure and performance, an investigation of thermal and visual comfort in the post disaster reconstructed schools is carried out with the following goals.

- To explore and overview thermal comfort and visual comfort of type design of school building.
- To analyze thermal comfort and visual comfort of type design using ecotect as simulation tool and students' responses to these condition in their classrooms.
- To come up with design recommendation to improvise thermal and visual comfort of school building.

3. Literature Review

School is a building which has four walls – with tomorrow inside. – Lon Watters The concepts of grouping pupils and providing knowledge to them have existed from the ancient time. It can be seen in ancient Greece, ancient Rome, ancient china and ancient India. The school building is developing from various era, more or less each has era has its own merits and drawbacks. At present ASHRAE continues to investigate on thermal comfort and its effect on students' performance whereas the introduction of mixed mode system is also one of the development to provide thermal comfort [3]. The paper further explains that there is no need for new high-tech systems, but rather a high level of follow-through, occupant education and communication, and tuning to ensure that systems are functioning as planned. This design target faces a particularly difficult path, however, given that it is a performance goal, rather than something that can be accomplished by the end of the construction phase of a building.

Comfort standards (ASHRAE 55, ISO 7730) state thermal comfort as accurate physical criteria for producing acceptable thermal environments, which include temperature, air movement, and humidity that Thermal comfort is a human's perception of comfort with respect to objective measures, such as temperature, humidity, and air velocity whereas factors affecting personal comfort include Gender, Age, Race, Size, Weight metabolic rates, Insulation through clothing etc. A study of 75,000 New York City students showed a 0.2% decrease in test scores for every 1°F increase in temperature. Students citing their classroom as 'comfortable' achieved 4% more correct answers in a math test compared to those who were hot, according to a survey of more than 4,000 Finnish students .Each 1°C decrease in classroom temperature showed a 12–13 point increase in math scores in a study of more than 3,000 US students [4]. [5] presented results of thermal comfort and environment quality in 21 school building rooms which highlight the importance of post occupancy evaluation and suggest that the information has important implications for how buildings are designed, built and operated to increase occupant comfort and productivity. [6] carried out research of Portuguese secondary classrooms in the city of Beja which has temperature of above 35 degree in summer and 10 degrees in winter without no HVAC system active where the result showed that the students found temperature range beyond the comfort zone acceptable and revealed the occupants' accommodation to carbon-dioxide acceptable and moreover it was verified that running on naturally ventilation mode, carbon-dioxide concentration limits were highly surpassed.

According to [7] the significance of thermal comfort study is related to the relationship between the occupants' satisfaction in the built environment, the functioning of the building, and energy consumption. Visual comfort is defined in the European Standard [EN 12665:2011} as a subjective condition of visual well-being induced by the visual environment[8]. The paper further explains Visual comfort depends on (i) the physiology of the human eye, (ii) the physical quantities describing the amount of light and its distribution in space, and (iii) the spectral emission of the light source. Visual comfort is related to both artificial and natural lighting, the area will be more focus on providing day lighting for the school building. Day lighting is a process that makes use of daylight to achieve some expected lighting effects in buildings, such as lighting up a task area, highlighting some objects while obscuring others, or even totally avoiding its contribution under particular circumstances, and also in large measure, "the art and science of day lighting is not so much how to provide enough daylight as how to do so without its possible undesirable effects"[9]. Moreover, the works reviewed in this paper, and discussed in seem to converge towards the need to introduce suitable devices to shade direct sunlight and avoid glare issues, while also allowing good illuminance levels. The author explains that finally, few recent studies have tried to integrate thermal and visual comfort in the design of educational premises.[10]

Among the concerned buildings, academic buildings house the largest occupied indoor environment after homes, making them particularly relevant to the issues of energy and indoor environmental quality. Such buildings require more attention because of the large numbers of people they can accommodate with different purposes such as teachers, researchers, and students engaged in space-time activities [7]. [12] revealed that only 48 papers on the topic of thermal comfort in school buildings were published from 1969 to 2015.[9] in research conclusion explains that integrating thermal and visual comfort is actually difficult task; suitable new comprehensive metrics may be needed in this direction, in order to help researchers to identify the best compromise between the two.

4. Methodology

The methodology is based on both Quantitative and Qualitative survey. The research is grounded on an overview of relevant literature review, which is complemented by information or data gathered during discussion and interviews on site area. The qualitative data is gathered through individual interviews (students and teachers,) using semi-structured and structured questions, while quantitative data is acquired from secondary source (books, reports, internet). Case study is followed by the observation, interviews and comparing it with information provided by literatures. While performing the case study, a conceptual structure, patterns, consistencies is discovered which played vital role in thought process. The survey was carried out among the post occupants of the school building i.e. Students and teachers. During research, occupants' post occupancy evaluation with objective data collected in situ and ECOTECT is used as simulation tool.

Software implementation: The Climatic data were collected from Department of Hydrology and Metrology which were analyzed on Weather Tool 2011 and later used in ECOTECT simulation. The building is simulated under natural ventilation creating various cases as Case A, Case B, Case C and Case D changing building envelope, Orientation and Openings. Thermal analysis is performed for the year to calculate discomfort hours and passive gains whereas daylight levels is calculated on the basis of illuminance at a point over a work plane.

Field Study through Questionnaire-based Survey: For the better understanding of thermal comfort and visual comfort conditions in the indoor space of the typical classroom, a questionnaire-based survey was carried out, involving a large number of users, i.e. students and teachers, in the four secondary school buildings sponsored by Japan International Cooperation Agency (JICA) at Lalitpur district during February, 2020 during school hours. A comprehensive questionnaire survey was created as a methodological tool, appropriate to gather all the data expected to

1. How do you feel about the temperature in the classroom at this moment?
   यस समयमा तपाईलाई कक्षाकोठाको तापक्रम कस्तो लाग्छ?
   • Cold (चिसो) • Slightly cool (थोरै शीतल) • Neutral (तटस्थ) • Slightly warm (हल्का न्यानो)
   • Warm (न्यानो) • Hot (तातो)
2. What do you like to be? तपाईलाई के मन पर्छ?
   • Cooler (शीतल) • No change (परिवर्तन छैन) • Warmer (न्यानो)
3. How do you feel about the air velocity at this moment? यस समयमा तपाईलाई कक्षाकोठाको हावाको वेग कस्तो छ?
   •Too still (धेरै गतिहीन) •Slightly still (हल्का गतिहीन) •Just right (सहि) •Slightly breezy (हल्का हावा)
   •Too breezy (धेरै हावालो)
4. How do you feel about the humidity in the classroom? यस समयमा तपाईलाई कक्षाकोठामा आर्द्रताको बारेमा कस्तो लाग्छ?
   • Much too humid (धेरै धेरै आर्द्र) • Too humid (धेरै आर्द्रता) • Slightly humid (थोरै आर्द्रता) • Just right (सहि)
   • Slightly dry (थोरै सुख्खा) • Too dry (धेरै सुक्खा) • Much too dry (धेरै धेरै सुक्खा)
5. Describe your visual comfort in this room when only depending on natural lighting during.
   यस कोठामा तपाईंको दृश्य सान्त्वनाको वर्णन गर्नुहोस् "केवल प्राकृतिक प्रकाशको समयमा".
   • Dark अँध्यारो • Bright उज्ज्वल
6. Is natural lighting alone enough to light this room? के प्राकृतिक प्रकाश मात्र कोठा को लागि पर्याप्त छ?
   • Inadequate (अपर्याप्त) • Adequate (पर्याप्त)
7. Do you experience glare sensation? के तपाई चम्किलो अनुभूति महसुस गर्नुहुन्छ?
   • Never (कहिले पनि छैन) • Always (सधैं) • Sometimes (कहिलेकाँही)
8. Do you switch on the artificial lights during the daytime? के तपाइँ दिनको समयमा कृत्रिम बत्तीमा स्विच गर्नुहुन्छ?
   • Never (कहिले पनि छैन) •Always (सधैं) •Sometimes (कहिलेकाँही)

Figure 1: Questionnaire on the Thermal and Visual comfort)

address the reason and objectives of the study. So as to lessen measurement errors and to build up validity and dependability of the outcomes, the development of questions depended on universal recognized practices. The semi structured questionnaires were prepared on the basis of research objectives which were surveyed on sampled population. Respondent were requested to write their name, class, age, gender, position in the classroom at the top of questionnaire, clothing ensembles and their activity during last 15 minutes. The survey carried out for TC by using questionnaire technique, which was adapted from Wong and Khoo and has been used in the previous study [11] whereas VC questionnaire was prepared from research paper [12] which was then translated with google translator to aid the students. Figure 1 shows the description of TC questionnaire from 1-4 and VC questionnaire from 5-8. The questionnaire included parameters such as thermal sensation vote (TSV) , thermal preference, air relative humidity and air velocity for TC analysis whereas for VC analysis visual comfort in classroom, natural lighting comfort, glare sensation and use of artificial light were examined.

5. Case Studies

The Survey was conducted in the four schools as shown in Table 1, Shree Mahakali Devi HSS, Pathpradarshak SS, Gupteshwor Ma Vi and Tika Vidyashram Uchha Ma Vi which are reconstructed after earthquake 2015 and are under operation. The schools are government school which are used for the teaching and learning purpose. The classroom building are three storey and has 3 bays in Mahakali devi HSS and Pathpradarshak SS whereas 4 bays in Tika Vidyashram and Gupteshwor Ma Vi. The locations of schools are spread out from the city center to suburban and then to rural areas.

Pathpradarsak School was chosen for the simulation because it is representative of a large number of relatively other type design building constructed. Figure 2 shows ground floor plan and figure 3 shows perspective photograph of selected school.The building has a reinforced concrete structural frame

Table 1: Showing list and general details of Surveyed school

School Name	Location	Classes	Total No.of Students
Shree Mahakali Devi HSS	Bhattedada-2 Mahankal kholsa	6,7,8	145
Pathpradarshak SS	Badikhel-2 Dautatar	8,9	333
Gupteshwor Ma Vi	Nallu-3 Sundarpani	7,8	140
Tika Vidyashram Uchha Ma Vi	Lalitpur N.P. -2 Sanapa	6,7	325

with 9mm brick wall with Steel glazed shutter windows and Doors Pressed steel panel door shutter. The selected classrooms 9 at top floor,8 at first floor and teacher room at ground of academic building were chosen for simulation.

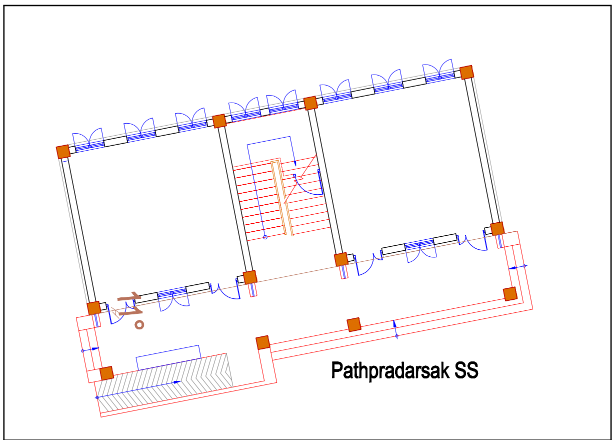

Figure 2: Ground floor plan of Pathpradarsak SS

Figure 3: Pathpradarsak SS school building (south view)

6. Data Processign, Analysis and findings

The simulation methodology followed allows the holistic evaluation of the thermal and visual comfort conditions while survey analysis further safeguards the validity and reliability of the results.

Analysis of ECOTECT Simulation: The analysis of the simulated results is divided into two parts. The first part includes the thermal comfort, while the second part considers the daylight performance metrics. Three main cases as A,B and C are analyzed with one additional case as D. The materials for analysis were chosen as shown in Table 2 for various three cases. Case A is base case where the simulation was done without changes on existing building which showed 732.6 hours discomfort in a year. The maximum heat 72.4% is gained due to Sol air temperature of the annual heat gains and maximum heat i.e. 72.1% of heat is lost through ventilation. Then in case B building envelope were replaced by various material which are noted effective by other studies which showed 702.1 hours discomfort which showed approximately 2% lesser from base case. The maximum heat 41.9% is gained due to internal gains whereas 88.5% loss through ventilation has a large impact on heat loss in winter because of the necessity of ventilation for air. On second phase the optimum orientation was also experimented in case B which did not show significant improvement. Similarly Case C is then created with the aim to improve both thermal and visual comfort. Hence in this case C conventional parameter were supplemented which showed discomfort hours to be 569.5 hrs. The maximum heat 73.4% is gained due to Sol air temperature and maximum heat i.e. 72.0% of heat is lost through ventilation.Later Case D was created replacing wall materials in Case C. Rammed earth for wall was replaced by Hollow Concrete and Autoclaved Aerated Concrete (AAC) block which claim to be cost effective and energy efficient. Hollow Concrete block showed discomfort hours to be 604.1 hrs. whereas use of AAC block showed discomfort to be 600.2 hrs. Figure 4 shows the change in percentage of discomfort hours annually due to both heat and cold along with their sum. Figure 4 shows comparison between various four cases and shows that with the change in building materials, there has been decrement in the discomfort level.

Table 2: Materials used for different scenarios

Building Elements	Case A Base case	Case B Materials Alteration	Case C Materials Alteration
Walls	230 brick wall	230 Cavity brick wall	300 mm rammed Earth
Windows	Single Glazed Cast iron frame	Double glazed aluminum frames	Single plane glass with aluminium frame
Doors	Cast iron frame and panel	40 mm thick hollow core plywood	40mm thick foam core plywood door
Floors	150mm Suspended Concrete floors	150mm Suspended Concrete floors	150mm Suspended Concrete floors
Ceiling	Suspended Concrete Ceiling	Suspended Concrete Ceiling plus with 50mm insulation.	Suspended Concrete Ceiling plus with 50mm insulation.
False Ceiling	Plastered Cement board	Plastered Cement board	Plastered Cement board
False Walls	Plastered Cement board	Plastered Cement board	Plastered Cement board with polystyrene
Roofs	Corrugated Galvanized Iron sheet	Decra Roofing	Decra Roofing

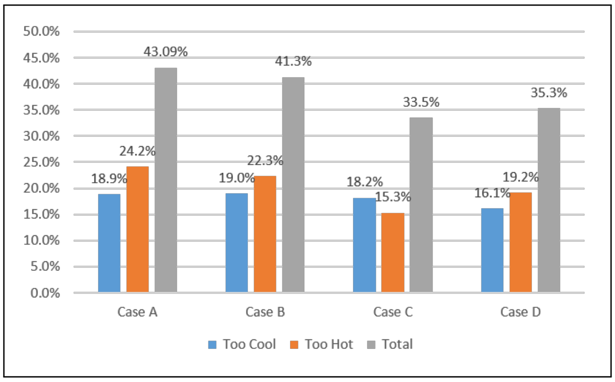

Figure 4: Thermal discomfort hours Comparison between Case A, Case B, Case C and Case D

In order to evaluate the visual comfort Case A and Case C was taken where the day lighting analysis was done. In order to investigate daylight conditions, indices namely Useful Daylight illuminance from 100-2000 lux since UDI method is considered to be more accurate from previous related studies. The day lighting analysis is also done in ecotect simulation tool which enables user to have a better insight into the conditions in each room separately during the year using climatic data. Each classroom from ground floor, first floor and top floor were taken. The area of the classroom with the lowest lighting levels is the area in the proximity of the doors i.e 81.66 lux when doors are remained closed. The area with the highest lighting levels is the area in the proximity of windows exceeding 2000 lux but this do not cause problems since light received at this portion is from north direction . The area in the center of the classroom exhibits average lighting levels. The minor issue was noted in the case of daylighting and henceforth least changes were made to achieve visual comfort without compromising the thermal comfort. In Case C doors were given the transparent glass at the top which indicated 169 lux as most reduced lighting level in class which is satisfactory.

6.0.1 Analysis of Field Research Results

A qualitative assessment of the thermal and visual comfort in a typical classroom is achieved through a field study research. The majority of students and teachers, i.e. 89.6% and 10.4% respectively, evaluated thermal comfort and natural lighting, in terms of different parameters as discussed below.

Students' response to the Thermal sensation vote (TSV): Students' response in the classrooms based on the indicator of thermal sensation votes can be seen in the figure 5 where it is clearly seen that the number of respondent feeling cold has high votes in all three schools. The distribution of thermal sensation votes, range mostly from cold to slightly cool .Interestingly, some of students of Shree Tika Vidyashram SS voted for warm and hot. This might be because the survey was carried out after their playing activites at lunch break.Thermal preference votes can be seen in Figure 6. The figure shows that majority of respondents preferred the air temperature in the classrooms to be increased whereas some of

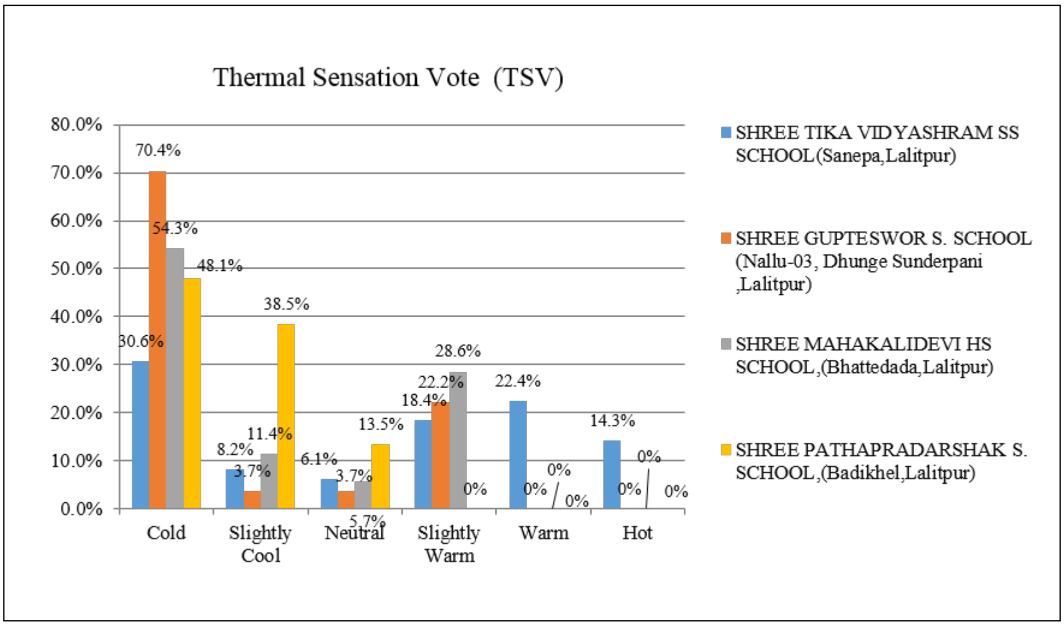

Figure 5: Percentage of Thermal Sensation Vote

them prefered it to be cooler. The reason seeking for cooler environment in february might be because of their activities and clo value. Similarly response to the airflow in classrooms based on indicators air velocity votes' can be seen in figure 7. The figure shows that the majority of respondents i.e. 82.9% felt slightly breezy since the rooms were provided with the cross ventilation system. This may indicate that the existing natural ventilation was able to supply enough airflow in the classroom. Respondents' responses to the air humidity condition in the classroom based on humidity votes can be seen in figure 8. The highest voters reaching up to 92.3% in one of the school i.e. Shree Mahakali Devi HSS felt that the humidity was comfortable (just right) which clearly shows that the humidity in the classrooms met the voters' needs.

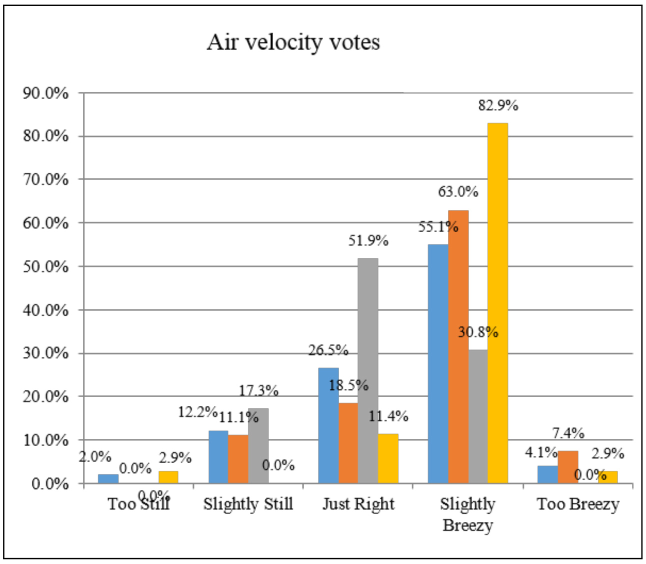

Figure 7: Air velocity votes

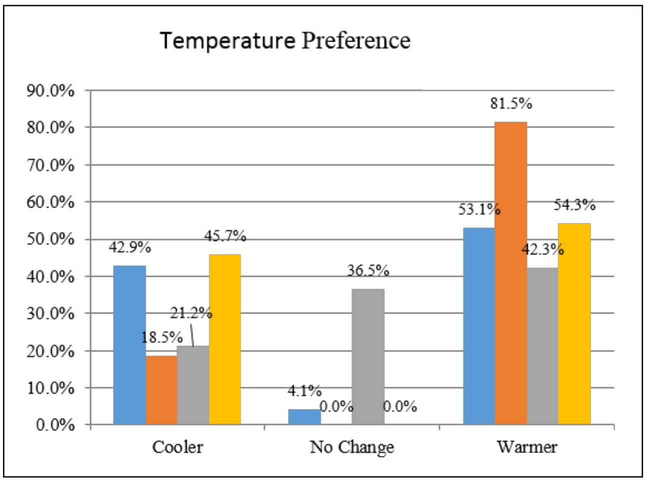

Figure 6: Thermal Preference

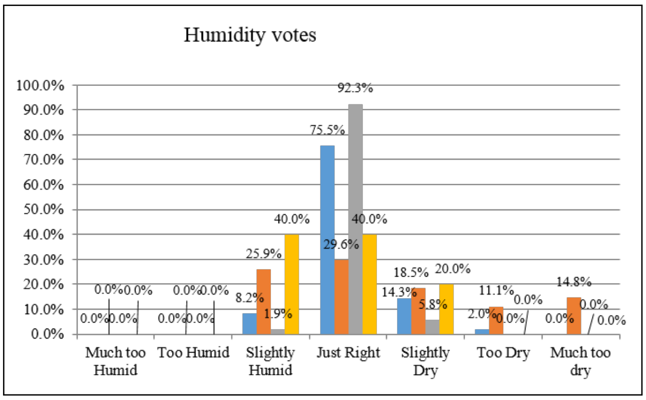

Figure 8: Air humidity response

Students' response to Visual Comfort: Response to the daylighting environment in the classrooms based on the indicator visual comfort can be seen in figure 9 left which indicates that the classrooms are brighter i.e. 100% student's acceptance and met the respondents' needs. Figure 9 right explains that the natural lighting is adequate for classrooms. Both figures in summary explain that the natural lights is adequate and are satisfied with the day lighting system provided in the building. Respondents to the visual comfort in the classroom based on the indicator glare sensation voted mostly for sometimes as shown in figure 10 left which indicates glare issues are caused from direct imposition of the sun's rays to the task surfaces, i.e. students' desks and classroom writing boards whereas the use of artificial light in the room has also voted mostly for sometimes as shown in the figure 10 right which shows artificial light is sometimes used in the classrooms.

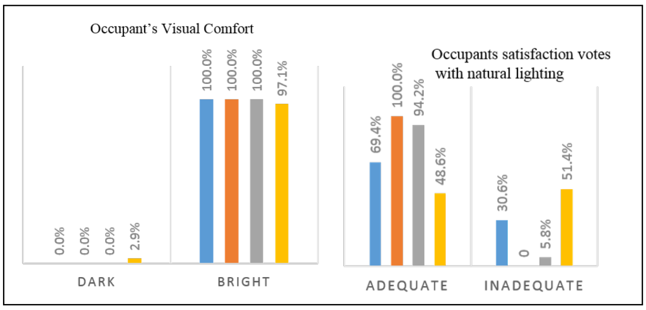

Figure 9: Visual Comfort Response (left) Day lighting acceptance (right)

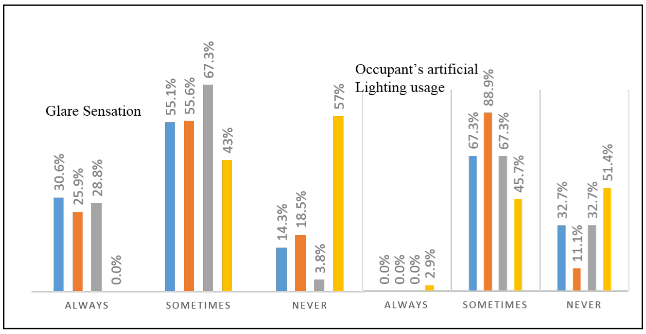

Figure 10: Glare Sensation Response (left) Necessity of Artificial light (right)

7. Discussion

Case A showed discomfort hours to be decreased by approximately 2 % only, when materials were altered and the orientation did not play any significant role to improve comfort. Case C was then created by using conventional materials and changes in openings which seemed to be effective to solve both lighting level problem as well as to decrease discomfort hours by approximately 10%. The ecotect analysis shows that the improvement in the thermal comfort can be done by changing the building envelope whereas visual comfort can be adjusted by adding glass on the door. Building envelope such as 300mm Rammed Earth decreased thermal discomfort hours and in case of unavailability of those materials AAC block and Hollow Concrete block can be used as alternative material. Single Glazing glass is preferable because no significant changes is made in analysis while using double glazed glass and single glazing glass are cheaper and easy to maintain .Insulation at the flooring and walls of Ground floor decrease discomfort hours in winter. GI sheet to be replaced by decra roofing and providing insulation at roof helps to eliminate heat during summer and heat loss during winter .Providing openings at attic, which is opened in summer for air circulation and kept closed during winter to prevent heat loss helps to balance thermal comfort in the building. The classroom condition of the surveyed type deign in month of winter shows that the number of respondent feeling cold has highest votes preferring warmer temperature in the class. These were data noted from students who were studying whereas the response of students after lunch and playing activities gave different figures showing that the number of voters feeling hot and warm . However, the students responded mostly for -3 i.e. cold which validates the ecotect result claiming maximum discomfort hours during winter. The variation on thermal sensation vote migh be duce to impact of clothing insulation and metabolic rate Air velocity was responded as slightly breezy because of the cross ventilation while humidity was voted mostly as alright. The research highlights that typical teaching spaces in type design ensure sufficient natural lighting levels throughout the entire year. This is due to high opening to floor ratio i.e. 30% and to the existence of bilateral openings on the two long facades of classrooms. Glare sensation is voted highest for sometimes by respondents which is indirect glare caused by reflections on the working surfaces and on the writing boards of the classroom. The direct sunlight glare due to excessive contrasts in the visual field of students is controlled at the site due to building orientation at North South and 2m overhanging's at the South. The study proposes improvements depending on the different building envelope, insulation, orientations and openings of the classroom in order to deal with thermal and visual discomfort problems, maintain acceptable comfort levels and eliminate energy consumption with the use of passive techniques.

8. Conclusion

The measurement of classrooms in the four selected post reconstructed type schools in the Lalitpur district has led to conclusion that the building presents discomfort in both summer and winter reaching highest discomfort during January.Thermal and Visual comfort can be managed by passive technique such as using appropriate materials, managing openings, insulation of walls and roofs, precise orientation but there still remains a problem in case of thermal comfort. In such cases thermal comfort can be achieved by opting for active technique. The winter discomfort can be decreased using heaters whereas ceiling fans can decrease the heat during summer.

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