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Climate responsive and safe earthquake construction: a community building a school

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Abstract

This article outlines environment friendly features, climate responsive features and construction features of a prototype school building constructed using green building technology. The school building has other additional features such as earthquake resistant construction, use of local materials and local technology. The construction process not only establishes community ownership, but also facilitates dissemination of the technology to the communities. Schools are effective media for raising awareness, disseminating technology and up-scaling the innovative approach. The approach is cost effective and sustainable for long-term application of green building technology. Furthermore, this paper emphasizes that such construction technology will be instrumental to build culture of safety in communities and reduce disaster risk.

Background

Schools provide the space to produce human resources which are required for betterment of the future of the world in all walks of life such as peace, safety, quality of living, technology, knowledge and philosophy. In addition to its central role as an education facility, schools also have a significant contribution to the community as they provide space for public purpose in a normal situation and it is also used as shelter in emergencies. Schools should be the model providing examples of quality education, better environment, safer physical facilities, and of social advancement and development. Activities in schools are the most contributing factors on children and their contributions are, in turn, reflected on the whole society. Schools facilities not only provide formal education or knowledge but also contribute to the social development, impartment of livelihood skills and nourishment of social norms. Schools should be like the field laboratory where children can see, explore, learn and implement. School is not only a provider of safer spaces for learning, but it also can act as a center to disseminate culture of safety and how

to make environment friendly physical facilities to the communities. 'School facilities, whether functioning well or not, serve as powerful pedagogical instruments'. If the power of these attributes as —three-dimensional text books was harnessed the impact on learning for the next generation of students would be limitless (Barr, 2011)."

Nepal's current literacy rate below 65 percent and Nepal needs to build 10,000 classrooms each year in order to meet the Millennium Development Goal of education for all. Nepal has net enrollment rate at primary level at 93.7 percent, net enrollment rate at lower secondary level at 63.2 percent and net enrollment rate secondary level i.e. grade 9-10 at 40.8 percent. By the year 2013, Nepal has target to increase the net enrollment rate at primary level to 97 percent, net enrollment at lower secondary level to 72 percent and net enrollment rate at secondary level at 46 percent (GoN, 2010). One of the major challenges of imparting education in Nepal has been observed as fewer enrollments in higher grades.

Introduction

One of the main factors which force the students to be absent from school is extreme indoor climate – hot and cold. The study in school of Bardiya, a district in southern plains of Nepal, on January 2007 observed very thin attendance in almost all the primary schools. 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 (Wangchuk, 2009-(Sonam Wangchuk, Green School to Promote Education for all in Nepal, report submitted to DOE Feb 2009). The situation is equally true in the summer as well. The hot classrooms in summer are a deterrent for the children to join the school, because their own traditional dwellings with thick thatched roof often covered with the foliage of creepers plants and cool earthen floors are many times cooler than the school with Corrugate Galvanized Iron (CGI) sheet roof (Figure 1).

It has to be noted that a comfortable indoor climate in school not only helps to retain students in the school but also contributes towards better performance of the students. Research has shown that the best temperature range and humidity for reading and learning is between 68°F and 74°F and 40-60%, respectively (Johnson et al, 2005). Issa et al. (2011) conducted a study aimed to compare a number of quantitative and qualitative aspects of usage across a sample of 10 conventional, 20 energy-retrofitted and three green Toronto schools. The statistical analysis to investigate satisfaction of teachers with the indoor air quality, lighting, thermal comfort and acoustics of their schools buildings showed that "teachers in green schools were in general more satisfied with their classrooms and personal workspaces' lighting, thermal comfort, indoor air quality, heating, ventilation and air conditioning than teachers in the other schools. Nevertheless, they were less satisfied with acoustics. Student, teacher and staff absenteeism in green schools also improved by 2–7.5%, whereas student performance improved by 8–19% when compared with conventional schools. However, these improvements were not statistically significant and could not therefore be generalized to all Toronto public schools. Whether these marginal improvements justify the extra cost premium of green buildings remains an active contentious topic that will need further investigation (Issa et al. 2011)." Recent academic research in Denmark, indicates that a temperature

reduction from 25°Celsius (considered hot in Denmark) to 20° Celsius resulted in an improved academic performance of primary level students of between 10% and 20% - all being equal and with other necessary educational resources available and good air circulation in place (Figure 2).

These studies underscore the fact that without proper intervention to make schools child friendly, comfortable, functional, safe and climate responsive, the notion of quality education remains as dream.

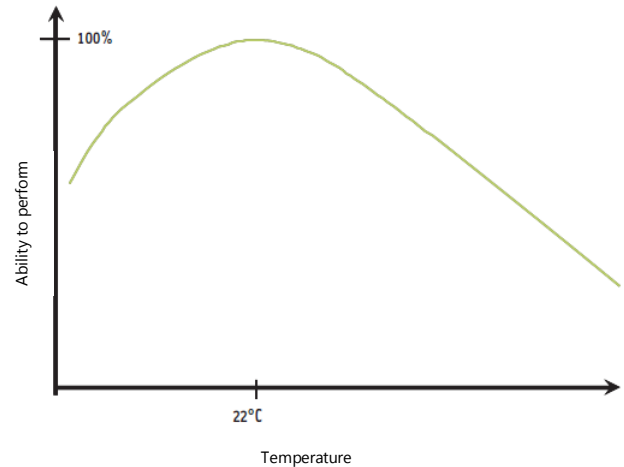


Figure 2. Classroom temperature directly influence students academic performances.

Source: HVAC bladnet nummer 8, 2006 - <http://www.techmedia.dk>

Despite of this fact, design and construction of school buildings in the whole subcontinent of Asia - whether it is India, Pakistan, Nepal or Bangladesh - has been a highly neglected area. Nepal has an elevation difference from 70 meter to 8848 meter from Mean Sea Level (MSL) in a short stretch of 200 KM in north-south direction. At present, existing school buildings in the Hill and Himalayan areas (elevation > 2000 meter from MSL) are terribly cold and unusable during winter season (four month), schools in the terai (elevation about 70 meter from MSL) on the other hand are very hot in summer season (four month).



Figure 1. A snapshot of a classrom and teachers room in a cold winter day in Bardiya, Nepal and a house of a poor villager (All images by Sonam Wangchuk).

The existing school buildings in terai are mainly of brick masonry having opening on most sides and a corrugated galvanized iron roof on top, which makes inside class room terribly hotter than outside during the summer. This forces the school authorities to change the normal school times and the school hours start early morning and close before mid day. The shift of school hours is not considered child friendly as children have to wake up in early morning and walk long distance to reach the school before they are even fully awake. Additionally, they have to walk back to home in the hottest hour. Climate responsive design is the one that would provide a comfortable indoor environment in response to the seasonal variations of the climate (Dilli et al). In National Environmental Guidelines for School Improvement and Facility Management in Nepal (NEGSIFM), 2004 listed indoor climate and comfort as main criteria.

Therefore, there is an urgent need to create a greater awareness of safer and climate responsive schools. At the same time, the schools in Nepal must be earthquake safe as the country lies in highly earthquake risk prone zone. The new schools need to have all five components of a school: Child friendly, safe against disasters, hygienic, environment friendly, fast to construct, economical and climate responsive.

In collaboration with Department of Education (DoE), Institute of Engineering (IoE) prepared a model prototype school building suitable for warm regions of southern Nepal (Figure 3). The project was supported by MS Nepal. This paper is based on the prototype class room school buildings built in the premises of IOE, Kathmandu, Nepal as a pilot project. Prototype class room building is built with Compressed Stabilized Earth Blocks (CSEB) and green roofing with bamboo and Compressed Stabilized Earth Tile (CSET) is used to

enhance its environment friendly and climate responsive features. The building is expected to be climate responsive (cool in summer and warm in winter), environment friendly, cost effective and earthquake resistant. The labor intensive techniques and use of local materials not only make the project cost effective and generate employment in the villages but also ensures community participation and empowerment in the vicinity. The construction approach and sequence is such that it also helps to raise awareness about environment and transfer the knowledge on green building technology to the communities. Additionally, the green and earthquake safer school buildings serve as three-dimensional textbooks to the students and "the school facility, including building and grounds, plays a large role in the curriculum program and culture of a school (Barr, 2011)."



Figure 3. The completed prototype climate responsive school building at the premises of IoE.

Material and Methods

Compressed stabilized earth blocks and environment friendly features

Most of the materials used in the construction of prototype - CSEB, CSET, timber, bamboo, straw, cow dung etc - are locally available and reduce the vehicular transportation significantly. The CSEB blocks need only curing in water and no firing is required. Therefore, the production of CSEB emitted eight times less carbon compared to fired bricks. Very little (6%) cement is added in CSEB for stabilizing and even this can be replaced by lime which is easily available in Nepal. Lime is carbon neutral and together with earth we get a very clean building material which is healthy for the environment. The comparative advantages of use of CSEB over commonly used fired bricks are listed in Table 1 below. Furthermore, the energy consumption during operation of such buildings is far less because of the climate responsive features listed in section beside.

Production of CSEB

Soil earthen block are not a new material, it has been used as construction material since 18th century and is in practice all over the world.

Table 1. CSEB has these advantages compared to fired bricks.

Pollution emission (Kg of CO ₂ /m ²)	Energy consumption (MJ)			
7.9 times less than country fired bricks	15.1 times less than country fired bricks			
Ecological comparison of building materials				
Product and thickness	No of Units (per m ²)	Energy consumption (NJ per m ²)	CO ₂ emission (Kg per m ²)	Dry compressive strength (Kg/cm ²)
CSEB-24 cm	40	110	16	40 - 60
Wire Cut Bricks-22 cm	87	539	39	75 - 100
Country Fired bricks-22cm	112	1657	126	30 - 100
Concrete blocks-20 cm	20	235	26	75 - 100

Note: Wire Cut bricks are also called Kiln fired bricks.(Source: Development Alternatives 1998)



Figure 4. CSEB production: Mixing of soil, compression in the Auram3000 machine, laying for curing and laying the blocks in the wall

Since its emergence in the '50s, compressed earth block (CEB) production technology and its application in building has continued to progress and to prove its scientific and technical worth. CEB production meets scientific requirements for product quality control, from identification, selection and extraction of the earth used, to quality assessment of the finished block, procedures and tests on the materials which are now standardized. The setting up of compressed earth block production units, whether on a small-scale or at industrial level, in rural or urban contexts, is linked to the creation of employment generating activities at each production stage, from earth extraction in quarries to building work itself.

The production of CSEB involves selection of soil, mixing of soil with proper composition of different percentages of clay, sand and gravel, silt and cement, pressing the mix in compressor machine and curing the pressed block for at least 28 days (Figure 4).

As the soil in the vicinity of IoE premises was found not suitable for construction of blocks, soil was transported from nearby areas (it should, however, be noted that in the real construction site this should be avoided as far as practicable). The soil had following composition as obtained from soil report: gravel 1.12 percentage, sand 78.16 percentages, silt 19.72 percentages and clay 1 percentage. About 15 percent clay was added from another soil as clay percentage was very low in the soil and another 5 percent of cement was added as stabilizer.

CSEB in Nepal

Attempts were made to introduce it in Nepal decades ago; however it did not seem to have picked up. The reasons seem to be partly the prejudice in our minds against earth as an inferior and 'backward' material as compared to cement, which is considered an 'advanced' material. Recently, in Bardiya, for the construction of green school (Action Aid program) established the production unit and produces blocks of different forms, from plain blocks for normal walls to hollow blocks for earthquake resistant construction, U blocks for lintel and ring beams, coping blocks for the top of a wall and even tiles for the floor and roof.

Green and climate responsive buildings

The design and construction of building should be based on Bioclimatic Design or Climatic Responsiveness, use of local material and technology, and community participation as far as practicable. The main criteria that make architecture green are:

- Use of material and constructional technology that is indigenous, has less embodied energy, and environment friendly
- Architectural design that assures comfort and human health with utilization of natural forces such as use of passive solar features and less use of active energy system such as HVAC
- Incorporation of renewable Energy System in the building to get high quality energy (such as water heating and electricity)
- Conservation of water in the building system itself

- Self incorporated storm water management system so that it harms the environment less and assures ground water recharge
- Self incorporated waste management system that reduces, reuses and recycles waste to make less waste-burden to the environment
- Healthy indoor air quality through use of healthy constructional material and proper natural ventilation

There are many features in a building that contribute to the comfort. "Elements impacting thermal comfort are building envelope, outside air treatment, temperature and humidity control, and air distribution. A preferred air distribution system for a classroom is under floor supplies with high exhaust / return grilles. Unfortunately preliminary studies or the first value engineering session typically try to rule this option out due to higher construction costs. Hence, distributing from the ceiling and returning low is sometimes utilized as a compromise (Johnson et al, 2005)." The prototype construction was planned, developed and constructed in order to realize most of the above features. Special attention was given so as to ensure that the process is simple, replicable and environment friendly. The school is designed to be relatively more functional and comfortable in all seasons. This is expected to have effect not only on the comfort and health of the children but also on their attendance, academic performance and efficiency.

The main components of the prototype which makes the building climate responsive are: solar orientation, passive solar gain, light shelf, earth berming and evaporative cooling. The designs considering above mentioned issues are relatively more comfortable and functional in all seasons.

Solar orientation

The orientation of building is such as to maintain indoor temperature suitable both in winter and summer. The orientation of long walls is towards south, i.e. long axis stretching along east-west is favorable feature for both hot and cold seasons. In hot season (or region), short east and west walls reduces skin dominated heat load due to low-angle east and west suns that are extremely irritating. In cold season (or region), long south wall provides maximum exposure to the low angle south sun that allows solar gain through wall and fenestrations.

Passive solar gain (for cold regions)

The roof has been designed and constructed in such a way that it slopes downwards in the north so that the wall area is maximum in the south. In cold regions (Figure 5), addition to normal fenestration, there are corresponding sets of fenestrations above, the whole stretch of extra fenestration and wall being covered with polycarbonate sheet for maximizing radiant heat gain. The extra fenestration allows direct gain as well as light that provide diffuse natural light inside. The natural and passive climate control system of traditional housing style provides a comfortable indoor environment irrespective of the outdoor climatic conditions (Radhakrishnan. et al, 2011).

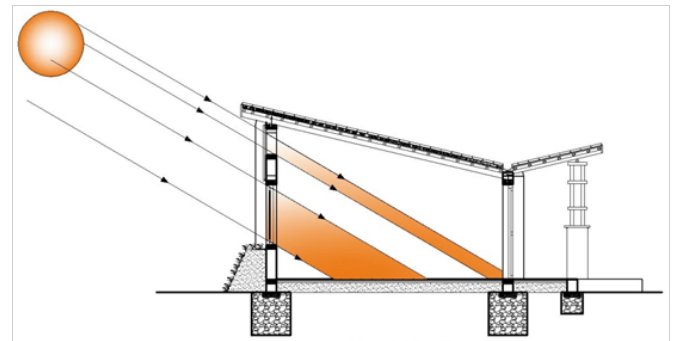


Figure 5. Direct gain of sun light in cold regions

The covered wall increases solar gain through solar entrapment that increases radiant temperature of wall inside. Though the radiant heat from wall is not directly used for increasing Mean Radiant Temperature (MRT) for thermal comfort as the wall in doesn't face occupants, the stored heat reduces heating requirement that would otherwise be needed to heat up cold walls by the sun, which would loss the credibility of the first hour sun. The U-value (thermal transmissivity) of CSEB is more than the normal U-value demanded for the light weighted insulative envelope. So somehow capacitive insulation is desirable than resistive insulation. This is possible as the same quality that becomes reason for the decrease of insulative resistance of CSEB is also the reason for the increase in capacitive resistance because high density compact materials are poor resistance but good thermal mass.

Light shelf

There is contradiction, especially in colder region, between the direct solar-gain that favors direct contact of human body with the solar radiation, with the glare created due to the same reason. Glare should be avoided not because it is just uncomfortable but because it is adverse to human eyes. The continuous exposure to glare can contribute in impairment of human vision. This can be solved by using curtain on the window that converts 'hole allowing direct beam radiation' to 'uniformly lit light source' analogous to 'plane' source of light. It is usually good to get diffused light from the left in the school as students are usually right handed. However, the students closer to the window shadow the students further. It is better if light is provided from the ceiling because there is less chance of obstructed light. Carefully designed sun shading can provide visual comfort, minimise heat gains and maximise thermal comfort whilst reducing plant requirements, energy consumption and carbon emissions (Clare et al, 2009). So the concept of light shelf is to provide diffuse light out of direct solar beam radiation by twofold reflection: one on the shelf and the other on the ceiling.

Earth berming

The constant temperature of the earth few meters below the surface can be used to create thermal comfort condition on the account of the fact that human acclimatized comfort temperature is closely related

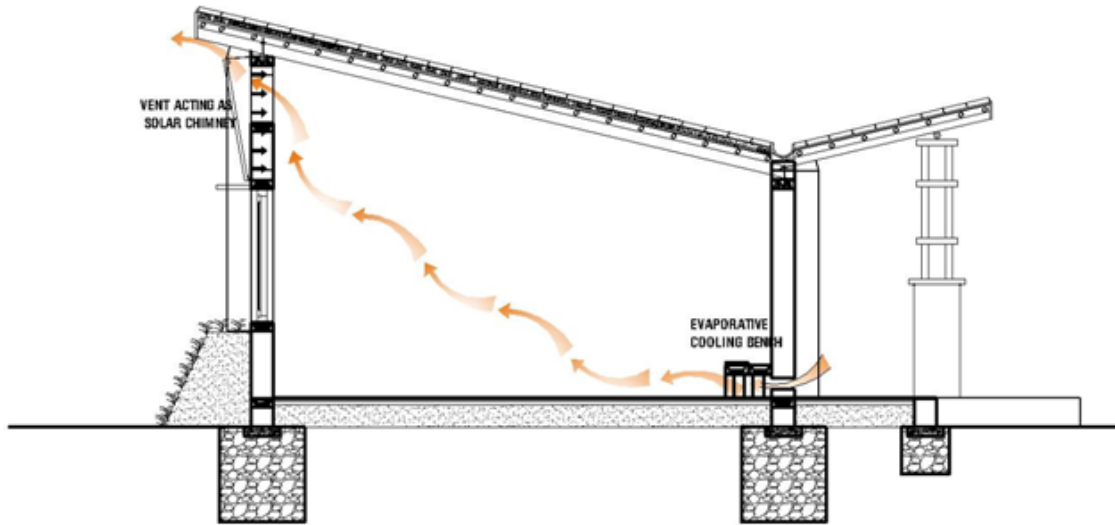


Figure 6. Combined evaporative cooling cum solar chimney

to the mean annual temperature that is retained inside the earth due to its large specific heat capacity. This fact is fully utilized only when the building is completely sheltered below the earth (called as Earth Sheltered House). However, some advantages can be taken by earth berming at least taking advantage of perimeter earthen insulation that prevents heat loss from perimeter of floor slab in case of cold regions or conductive heat transfer to the cool earth in the hot region. The earth berming also provides lateral support to the outgoing walls and acts as extra tie to the walls.

Evaporative cooling (for hot regions)

The same extra fenestration on the top of the southern wall used for the radiant solar gain in the cold region can be made open (of course protecting from rain) to allow hot air accumulated due to heat of sun and internal gain to escape out to draw air from the opposite side. This is what we call as solar chimney effect (Figure 6). The opposite side, here the north, is shaded and so air is relatively cooler and so natural convection takes place. In order to ensure the air entering the building really sensitively cooled down, the concept of cooling bench is devised, which underneath cools the air drawn from outside in the north through dissipation of heat as latent heat of evaporation of water. The cooling bench consists of wetted U-blocks that hold and distribute wetness to the support of bench. However, contact with structural wall is avoided. The Dear & Brager of the Center for the Built Environment at the University of California show that natural ventilation can also improve indoor environment quality compared to air conditioned systems as a result of higher levels of fresh air and greater occupant control (Dear et al, 1998). This combination of evaporative cooling cum solar chimney effect for convection provides comfort condition in hot regions.

Safer and earthquake resistant design

Nepal lies on earthquake prone zone and entire Himalayan belt falling in Zone IV, highest hazard, of earthquake risk. Therefore, it is essential that the design and construction of school buildings should

be earthquake resistant. The recent experience in Pakistan and China earthquakes, in 2005 and 2008, respectively, where an unusually large number of children were killed by collapse school buildings once again underscored the urgent need to build safer schools. The large number of people killed in different earthquakes around the globe is a reminder of the possible scale of disaster in Nepal. The children and people killed are not due to earthquake but due to poor design and construction practices - mostly due to construction of RCC structure without proper engineering input in design and construction.

The prototype building is designed as per earthquake resistant criteria for masonry structure. It has six horizontal tie beams starting from the foundation level ring beam (Figure 7). The others are at plinth level, window sill level, lintel level, roof level and finally at rooftop level. These are made of Reinforced Cement Concrete (RCC) cast inside U shaped CSEB blocks. It also has numerous vertical reinforcements - one at every 1.5 meters length of wall, each corner and also on each side of all openings like doors and windows. The six horizontal ring beams are tied together by the vertical ties make a structure a skeleton like mesh of reinforcement (Figure 7).

The idea is that the metal reinforcements bring ductility (flexibility) to the building and the building is able to absorb a lot of energy before a major damage. In the event of an earthquake it should get cracks but should not collapse completely. The collapse prevention feature in buildings is essential to save lives of the people inside the building. Apart from this, the CSET roof in bamboo mesh and timber rafter is lighter than a conventional concrete (RCC) slab roof which is advantaged as it decreases the amount of force coming in the structure and also will cause less fatality in case of collapse.

Fast to build

In addition to the above qualities, it is essential that the school construction is completed in short time in order to be considered as an alternative for the planned 50000 classrooms by 2015. The

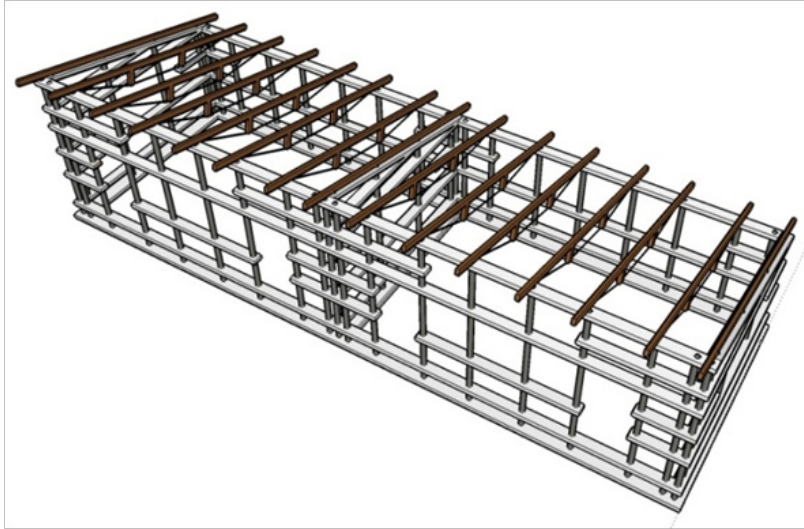


Figure 7. Horizontal and vertical ties along with roofing rafters as a cage system in the building design.

construction of the prototype from foundation to final finish took 20 days. It was carried out by 17 masons roughly 30 labour/volunteers each day and 2 supervisors. This does not include time for production of CSEB, CSET, door and window frame and truss, which were made in advance or supplied by manufacturer. The making of blocks and tiles were carried out by an average of 4 masons and 20 labour/volunteers in roughly 20 days. When the processes are mainstreamed for mass application, this can easily be reduced significantly.

Cost effective

The cost of a CSEB block with CSET roof of 100 square meter plinth area comes to roughly NRs 0.9 million on 2008, which is comparable to the Department of Education cost for a conventional brick masonry CGI roof school. In fact a significant part of the cost of this building goes towards the steel and cement used for earthquake safety features, otherwise with lower earthquake safety features it would easily be cheaper than the conventional school design. Furthermore as the construction is labour intensive is possible for the villagers to contribute voluntary labour and some wood, locally made CSEB thus the actual cash requirement might be less than in a conventional school.

According to Auroville Earth Institute CSEB blocks are most of the time cheaper than fired bricks. This varies from place to place and specially according to the cost of cement. The cost break up of a 5% stabilised block would be roughly as follows, for manual production with an AURAM press 3000: Labour: 20 - 25% Soil & sand: 20 - 25% Cement: 40 - 60% Equipment: 3 - 5% In the context of Auroville the following cost comparison was found— A finished meter cube of CSEB masonry is always cheaper than fired bricks: 19.4% less than country fired bricks and 47.2% less than wire cut bricks (Auroville, 2004).

On other hand, the green school construction will contribute significantly on economy of country. The construction material such as roofing material CGI sheets or UPVC sheets are imported either

from India or China required lot foreign currency. Apart from being an environmental challenge and a big drain on Nepal's economy, the life of both the UPVC sheets and GI Sheets is only 30 years. On the other hand the life of a CSET roof is many more years and also sustainable. This will help to save its precious foreign currency reserve by reducing the import of CGI sheet from India and UPVC sheet from China.

Technology transfer through proper use of local material and appropriate technique

Most of the materials of prototype class room building are available or can be produced in Southern belt and hill. Both the construction material and technique are known to people of Nepal for many years.

Participation, empowerment, employment

The construction technique of green school is labor intensive and it offers the possibility of creating employment for thousands of masons and skilled labor provided the project is implemented at a large scale. In this regard the school buildings later could inspire the local population to switch over from polluting and costly materials and that could generate thousands of green jobs for rural youth in their own regions. Due to the known material and technology, maintenance will not be a challenge to the local communities as in other type of construction.

From the educational point of view it could be a process of engaging the community to participate in education - first in the construction and then the resulting sense of ownership is expected to encourage the community to participate in the management of the school thereby ensuring accountability in the education system itself.

Community contribution is encourage mainly to make community to fill ownership and also reduce the overall cost of construction. For this reason the process of this participatory school construction involved meetings, gatherings and orientation sessions with the community at various stages of construction.

The process of community engagement

The engagement of the community is a key to this participatory school construction movement. Engaging community from the conceptualization and planning phase of the schools is essential for their sustainability. A review report of high performance school in the US suggests that "community planning process has yielded an increased emphasis on sustainability that is evident in several new school buildings (Bernstein et al. 2003)." Although the prototype school building didn't require community participation, school planning process in real situation requires community participation. At least four formal meetings with the village leaders and communities is essential. In the first meeting, mainly village leaders and teachers are invited to present basic features of the green building and how it can be used to improve the educational status of the village. Usually this meeting is a bit challenging with many questions, doubts and sometimes misunderstandings as people are not aware about the CSEB and green construction technique. After convincing to the village leaders and teachers, second meeting to be carried out to present the basic concept and benefit to the community and also discuss on plan, elevation, location and possible community participation.

The third and fourth meetings to be carried out closer to the time of the construction; leader level meeting followed by a general public level meeting to discuss the design and the logistical and technical issues of construction. At this time the villagers to establish the School Construction Committee (SMC) and take the responsibility of volunteer mobilization and organization as well as the arrangements for the visiting masons.

Disaster risk reduction through schools

The outcome of investing in green and safer schools may have broader impact in the communities. The construction of disaster resilient school will provide an opportunity to raise awareness among the communities for culture of safety. The notion attached with the school project is that the buildings must be safer, user friendly, affordable and simple to construct. In most part of the country, access to technology is very much limited and large multi story construction is beyond the reach of the people. Therefore, simple and affordable technology is recommended.

The people killed in West Sumatra earthquake and Haiti earthquake had huge difference although the magnitude and epicenter distance are more or less same. As shown in table 2, in West Sumatra earthquake about 250000 building collapsed and only 1100 people were killed where as in Haiti earthquake about 900000 building collapsed/damaged but 2400000 people were killed.

Table 2. People killed and building collapsed/damaged in different earthquake

Earthquake	Magnitude and time	Building/damaged collapsed	People Killed
Sumatra	7.6 Richter Scale, Sept 30, 2009, at 5:16 pm	115000 houses collapsed & 135000 damaged	1100
Haiti	7 Richter Scale, January 12, 2010, at 16:53 pm	900000 – 1100000 shelter required	240000

The main reason of less number of death in West Sumatra was the typology of building as the majority of buildings collapsed were simple one storey rectangular buildings with light roof. Which shows the simple rectangular one storey building with light roof reduces significantly the death toll in the event of earthquake mainly because of light structure. The green school building with CSEB material will reduced death toll significantly in the school and the notion of one storey school building with local technology will be instrumental to increase awareness about building safer houses in the community.

Construction features

The design and construction of prototype building construction is based on Bioclimatic Design or Climatic Responsiveness, safe, and cost effective. The building is single storey with consist of 2 classroom. The built school in the prototype has only one usable room and other room is partly exposed for visitors to see the built-in features (Fig 8).

The main constructional features of prototype classroom building are as follows:

Foundation

Initially, four different options of foundation as in below were discussed in the Advisory Panel Meeting.

- Rammed Earth, developed by Auroville
- CSEB in stabilized soil mortar 1:4:8
- RCC strip
- Stone work in stabilized soil mortar 1:19

The analysis on selection of foundation type carried out mainly with the consideration of influencing factors; cost, cement requirement, possibility of unequal settlement, moisture penetration control, workmanship control, sturdy formwork and construction period. On the basis of above mentioned factors and also due to special consideration of the site being in doubt of water logged, it was decided to use stone work in Stabilized Soil Mortar 1:19. The foundation sized 70 cm depth and 75 cm width.

Wall

The wall was decided to construct out of CSEB blocks applying Auroville's technology. It consists of wall built out of 24 cm X 24 cm X 9 cm Compressed Stabilized Earth Blocks made out from Auram 3000 Press. The wall system has vertical ties at every corner: L-joints and T-joints. Also these are provided on the sides of each fenestration. The continuous wall has vertical tie in every level less than 1.5 meters. This is meant for avoiding lateral buckling due to long continuous wall.

Bands – vertical and horizontal

There are ring beams in plinth level, sill level, lintel level and roof level. These are connected to the vertical ties to give rigid box effect during earthquake. The ring beams are cast in situ out of U-blocks. The lintels are precast before they are made continuous with the lintel band during actual construction.

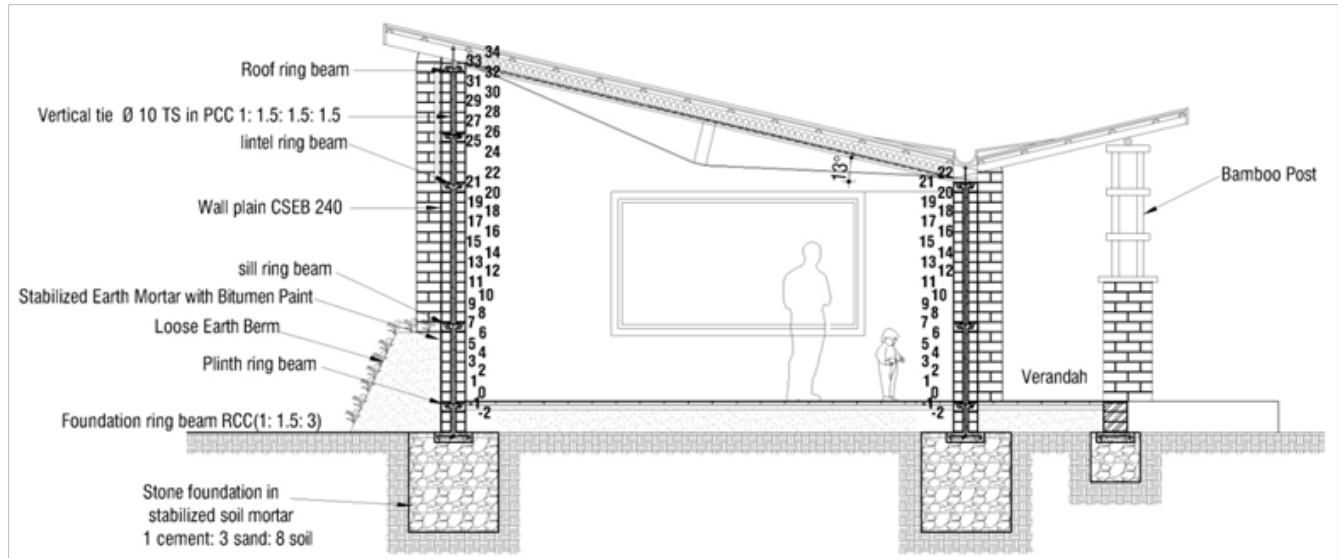


Figure 8. Drawing showing different elements of the prototype school building

The vertical ties and the ring beams consist of reinforcement of 2-10 mm diameter bars whereas the lintel consists of reinforcement of 2-12 mm diameter bars owing to more flexure that it has to bear from the above wall. The bands, at corners and T-joints, consist of extra bars of 10 mm extending 50 cm along each adjacent wall for additional reinforcement. The details can be seen in the figure. The stirrups of 8 mm bars are arranged in all case at spacing of 25 cm.

Roof

The roof has challenge to span 5.5 meters without use of truss that would otherwise invite costly non-green steel truss or heavy timber-consuming wooden truss. The solution to this problem was solved with design trussed beam section. A Trussed Beam consists of rafter sizing 7.5 cm X 12.5 cm with 12 mm diameter rod or high tensile steel wire pulling the rafter ends to be supported in form of triangle at the middle by 60 cm long and 7.5 cm X 15 cm section timber strut. The structural concept behind this is: the timber takes only compression and the steel takes tension. So small cross-section of rafter is sufficient; otherwise flexure beam has to take both compression and tension that demands large cross section. There are several Trussed Beams spaced 120 cm center to center that would support bamboo purlins above without deflection. Architecturally this gives single pitched roof. The purlins are spaced 35 cm center to center above which layed the bamboo strips transverse direction touched to one another. On the top of bamboo strip placed layer of plastic sheet for water proofing. This is followed by bamboo mesh that supports thick layer of mixture composed out of soil, cow-dung and straw that provides insulation to the roof. Then thin slurry of stabilized mud is layed that supports Compressed Stabilized Earth Tiles (CSET) made from the same machine.

Windows and doors

Windows and doors frame are of timber of 3 inch x 5 inch section. Timber is preferable as it is in common practice and available locally.

Verandah

Verandah is independent structure that stands in front of class rooms. There is no tie beam below as no severity was realized from earthquake viewpoint. The pillars of the verandah are two-third CSEB and one-third bamboo (or timber) with strut that supports the roof verandah above. Verandah can be used for outdoor classroom activities.

Rain water harvesting and low cost solar water heating

The roof of class room faces north and the roof of verandah faces south to meet at the notch of 'V'. This notch can be used to harvest rain water that can be supplied to the low-cost solar water heater. The solar water heater lies on the verandah roof that faces south.

Conclusion

As the school in this part of the world is common to all and also the centre of community activities, school may become learning center for environment friendly, disaster resilient and green house design and construction. In the same time with many environment friendly features the school building can provide a comfortable learning space in itself for the students and communities to grow up with and learn about ecological issues, climate change and sustainable development. Nepal, which is in high earthquake risk zone, needs to building additional 50,000 classrooms in order to meet the Millennium Development Goal of education for all.

Because of high earthquake risk in almost all the country, the priority should be given on proper design and construction to ensure the school buildings are safe and disaster resilient. Similarly, most of the places in Nepal have extreme climate condition both cold and hot, there is a need of design and construction technique on cost effective climate responsive structure.

The design and construction of Prototype classroom building is done to provide an alternative to current practices of adding school buildings which are neither comfortable nor disaster resilient. The nature of production and design technology not only address today's global warming issues, but also is instrumental for disaster risk reduction. In particular, by providing the climate responsive and safe school building will help to increase the attendance and enrollment of children in school. Furthermore, the process helps to create awareness among the communities and spreads the message of culture of safety. The prototype classroom – building with SCEB, SCET may be the best building type for the school construction as it ensures the basic need of school buildings:

- Climate responsive
- Environment friendly and sustainable
- Cost effective
- Fast to built
- Safe and earthquake resistant

This intervention will help to make schools/houses functional and comfortable in all seasons and in same time contribute lot on green movement. Ultimately this will help to minimize the carbon emission and unhealthy exploitation on earth for getting resources.

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