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Sustainable Design and Thermal Comfort Strategy: Cases of Urban "Affordable Housing" in Nepal

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Abstract
Affordable housing is commonly considered on a cost basis, while environmental and social issues are thought to be addressed separately or totally ignored. Housing planned and built within an integrated sustainability framework, will not only be more accessible to low-income households, but will also respond to their diverse social and cultural needs. Acknowledging this importance, the main objective of this study was to assess the sustainability of existing and claimed to be affordable housing with reference to three case studies. Therefore based on literature study, a list of 21 indicators with there respective key performance indicator was developed which were critical and suitable to Nepal's context. It was followed by the methodology on how those indicators were going to be assessed. Data for the study was collected through observation, questionnaires survey with the occupants residing in those case study housings and interview with key informants.

The findings from the survey revealed that the housing's prime concern while planning the neighborhood and designing the dwellings was the initial investment cost. The planning and design of those cases have followed the minimum standards for density, room size, area of openings etc. However, passive solar design, accessibility or thermal comfort has been least considered. Finally, on the basis of case study findings and literature review, this study then suggests sustainable strategy under all those listed indicators, while designing similar kind of affordable housing in hilly region of Nepal.

The study also investigates the relationship between building materials and indoor thermal environment of those cases. On the basis of the findings, the study recommends 8" thick HCB and CSEB as alternative walling materials and RCC filler slab and ventilated CGI roof with plastic bottle insulation as alternative roofing technology for indoor thermal comfort.

Keywords
Sustainable design – Thermal comfort – Affordable housing

1. Introduction

Housing is not only concerned with the design of a specific housing unit. It is concerned with the design of a whole housing environment which includes accommodation, jobs, education, health services, etc., in a context which is accessible, safe, hygienic, aesthetically pleasing and also sustainable [1].

The lack of secure housing for the urban poor has become one of the most problematic planning issues in most of the growing urban areas. According to Shelter Policy 2012, Nepal's housing deficiency would reach to 900, 000 by 2023, which implies annually we require around 90000 numbers of housing units to meet the target. Affordable housing can solve the urban housing problem to some extent. However, the providers are particularly concerned on ensuring appropriate housing within their financial means. Seeking to provide homes for financially disadvantaged people, environment and socio-cultural factors is missed resulting in a short term solution to housing problem. For example, the affordable housing projects in Haripur made for Koshi flood victims has been abundant by many occupants because of it being located very far from the city. Moreover, the houses delivered for the low income group indicates a lower standard of housing, seeing the compact building design and the use of lower quality of material. The building materials result in poor performance of the building and poor thermal comfort [2].

On the contrary, there also exists few community level housing projects in Nepal, which are claimed to be successful, affordable and sustainable. Therefore, the main aim of this study is to conduct a post occupancy assessment of those affordable housing from a sustainable perspective.

2. Research Objective

This research is intended to assess the “affordable” urban housing design status quo from a sustainable perspective and develop strategies to enhance sustainability and provide thermal indoor comfort to the occupants. However, the specific objectives of the study are as follows:

- To assess claimed to be “affordable” urban housing of Nepal from sustainability perspective.
- To investigate the relationship between building materials and indoor thermal comfort of those housing.
- To develop sustainable design strategies for similar kind of housing in hilly region of Nepal and recommend alternative walling and roofing materials and technology for indoor thermal comfort.

3. Methodology

The main research method used for this research is case study. The study area for this research is limited to affordable housing in urban hilly region of Nepal.

3.1 Selection of Case Study

Three different kinds of affordable housing projects were chosen for the case study namely, Paliphal Housing, Kirtipur, Samabesi- tole Housing, Pokhara and Karmachari Sanchayakosh Housing. Pokhara. Reason behind choosing Paliphal Housing is because it is the first project of its kind to address the issue of housing the urban poor of Nepal in environmentally sustainable manner. This project is said to be successful in addressing the issues of water shortage and in managing waste water. Karmachari Sanchayakosh Housing, Pokhara was chosen for another case study because it is a successful community housing project which has been constructed from sustainable building materials and technology. Therefore its study would provide with an overview of the impact of such materials and technology. Samabesi-tole Housing was chosen for the reason that it has been designed using community participatory approach.

3.2 Selection of Indicators

Table 1: Development of indicators and key performance indicators

Dimension	Indicators Definition	Key performance indicator
Environmental	Density	Dwelling unit density(no of dwelling in hectare)
		Population density of land area(hectare)(pph)
	Climate Responsive design	Orientation of dwellings
	Renewable Energy technology	Percent of household using PV panels for electricity
	Energy efficient appliances	Percent of household using energy saving CFL/LED bulbs
	Building materials	U-value of walling materials(W/m2-K)
		U-value of roofing materials
	Indoor thermal comfort	Indoor temperature (°C)
	Access to water supply	Access to improved drinking water
		Satisfaction with water supply
		Per day per person water consumption (in litre)
		Practice of rainwater harvesting
	Ground water recharge	Use of pervious pavement
	Solid waste management	Practices of recycle of solid waste
	Liquid waste management	Provision of grey water treatment
Economic	Affordability	Income range
		Monthly repayment
	Economic opportunity	Employment opportunity around the vicinity
Socio- cultural	Accessibility	Distance to work
		Distance to school
	Proximity to facilities	Distance to common facilities like bus stop, groceries etc
	Healthy indoor environment	Area of opening per floor area
		Opinion on natural light
		Opinion on natural ventilation
	Housing diversity	Variation in housing type
	Safety	Rate of anti-social activities
		Security from calamities
	Size of dwelling	Per capita floor area(in sq.m)
		Opinion on room size
	Community participation	Involvement in community groups(Mahila Samuha, Youth clubs, Co-operative etc)
		Community participation during planning and design
	Adaptability	Adaptability with time and need
	Open spaces	Availability of open space for various function
		% of open spaces

To fulfill the objective of the research, it was necessary to build a list of indicators under which the sustainability of cases would be assessed. An extensive and investigative theoretical review of relevant literature was conducted to derive a pool of relevant indicators as used in prior studies for the measurement of neighborhood level sustainability. The sustainable indicators were developed under three pillars i.e., the economic, environmental and socio-cultural. To validate the selected indicators, they were reviewed by a list of experts from various fields through emails. The following tables provide definition of indicators as well as describe their key performance indicators.

3.3 Data Collection and Analysis

The primary data was collected through field work which involved interview with key informant and case study of 3 different cases. The case study involved observation and questionnaires survey. Observation of all the selected cases included interaction with the residents, taking photographs, indoor temperature recording, video recordings, tape measurement etc. The observation incorporated a professional analysis of the settlement, including a focus on building conditions and the overall physical and social environment. Indoor temperature of few sample dwellings from all the three cases was measured. For finding out the relation of different roofing materials in the indoor temperature, the temperature was recorded from both the floors of Paliphal and Karmachari Sanchayakosh Housing.

All the primary and secondary data or information collected during case study was processed and analyzed by developing charts and graphs in Excel. A comparative charts and graphs for all the case studies helped to draw logical conclusions on the sustainability and thermal comfort of those cases.

4. Analysis and Discussion

The analysis looked upon all the selected indicators at both the individual dwelling and the community level. However, analysis and discussion of few major indicators has been included below:

4.1 Density

Table 2: Density Analysis

Dwelling unit density per land area (hectare)			Population density of total land area (pph)		
Paliphal Housing	Samabesi-tole Housing	KSH	Paliphal Housing	Samabesi-tole Housing	KSH
144.3	92.1	56.5	649	350	209

Figure 2 shows that dwelling unit density in Paliphal Housing is the highest of all followed by Samabesi-tole Housing and the Karmachari Sanchayakosh Housing being the least dense. To make this data more relevant to Nepalese context, in a ropani of land there are around 7.3, 4.7 and 2.9 dwelling units in Paliphal Housing, Samabesi-tole Housing and Karmachari Sanchayakosh Housing respectively. Even when the dwelling unit density(per hectare) in Paliphal Housing is as high as 144, the dwelling units are planned around open spaces making the planning less denser. Furthermore, the population per hectare of total land area (pph) for Paliphal Housing, Samabesi-tole Housing and Karmachari Sanchayakosh Housing has been calculated to be 649, 350 and 209 respectively. This implies that occupant's share on open spaces in Paliphal Housing is the least of all the other housings.

4.2 Passive Solar Design

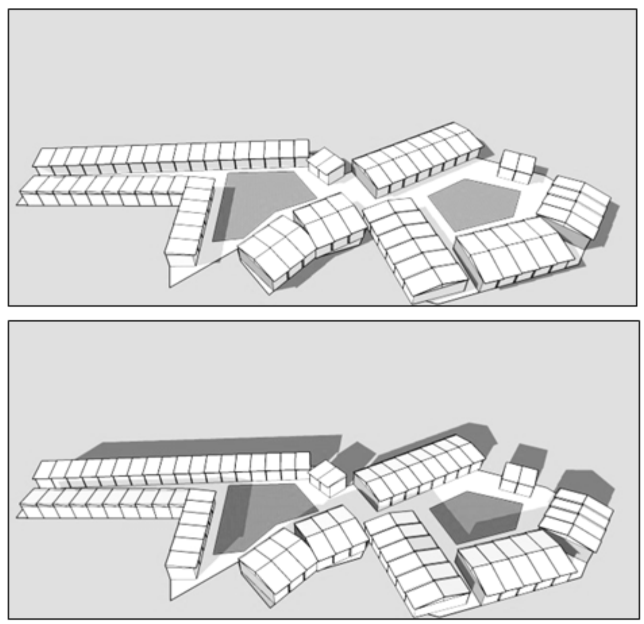

Figure 1: Shadow casted by the units during 15:00, Dec and 15:00, June in Paliphal Housing, Kirtipur

Affordable housing has an optimum size plots. Therefore designing the dwelling units considering passive solar design in itself is a challenging job. All the dwelling in Paliphal Housing, Samabesi-Housing and Karmachari Sanchayakosh Housing dwelling have access to winter sunlight because of being planned around the open spaces. However, the orientation of longer wall toward the south, for winter heat has been less considered. A good point in all cases is that the dwelling units are low rise, because of which they do not cast shadow on dwellings across the streets in winter (Figure 1).

The prevailing wind in Kirtipur flows from west to east direction. The planning of dwellings in Paliphal Housing has not considered the wind flow pattern. However the northern part of the housing is comparatively cooler in summer because of no structural obstacle in the north-west side. In case of Sambesi-tole housing, the site is sloped towards the east. This allows the prevailing wind to flow from the south-east to travel along the housing boundaries making the surrounding comparatively pleasant in summer. (Figure 2).

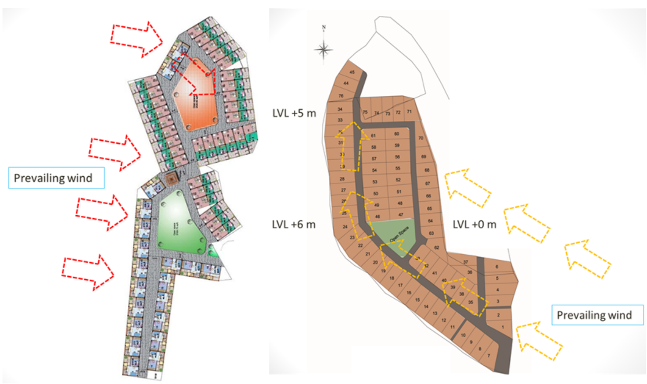

Figure 2: Prevailing wind flow pattern in Paliphal Housing, Kirtipur and Samabesi- tole Housing, Pokhara

4.3 Building Materials

Table 3: Building materials and their properties

	Paliphal Housing	Samabesi-tole Housing	KSH
Materials for walls	4" Burnt brick	8" thick hollow concrete block	8" thick hollow concrete block
Materials for roof	RCC for ground floor and CGI on the top floor	Combination of RCC and CGI	4" Precast RCC slab
U-value of walling materials(W/m2-K)	4.66	0.43	0.43
U-value of roofing materials	61	61	4.5

Table 3 shows that Samabesi- tole Housing and Karmachari Sanchayakosh Housing both are load bearing structure made up of 8" thick HCB. However, Paliphal Housing is made up of only 4" thick burnt brick wall. The deduction on thickness of wall can increase the interior space or in a mass planning it can even increase the number of dwelling unit. However, the U-value of 4" thick brick wall is very high as compared to HCB, therefore making the heat transfer easy. For the roofing material, Paliphal Housing has RCC slab for the ground floor and CGI sheet for the first floor. Similarly, Saamabesi Housing has a combination of RCC slab and CGI roof. The U-value of CGI sheet is 61 (W/m2-K), very high therefore allowing quick heat transfer to and from the building and therefore creating an unbearable indoor temperature, differing with the occupant's adaptive thermal comfort. When interacting with occupants in Paliphal and Samabesi-tole Housing, it was known that the occupants didn't prefer CGI roof. However, since it is cheaper, easy and fast to build, its use was dominant. But they also emphasized that they would like to replace it with RCC, once they were at a stage to afford.

4.4 Indoor Thermal Comfort

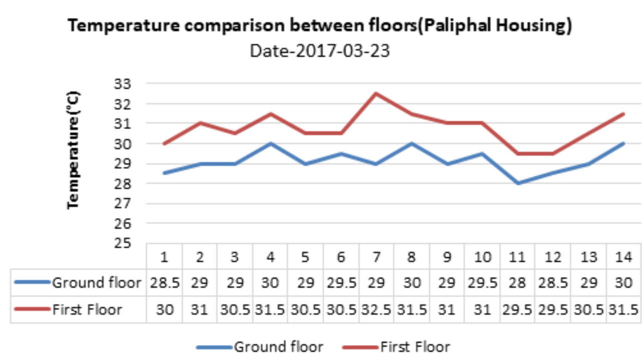

Figure 3: Temperature between floors in Paliphal Housing

The graph (Figure 3) exhibits relatively higher indoor temperature in the first floor of Paliphal Housing. The walling materials for both the floors are brick. But the roofing material for ground floor is RCC and for first floor is CGI. Heat transfer coefficient,U-value(W/m^2.C) for CGI and 110 mm RCC are 61 and 4.5 W/m^2.C respectively. The higher U-value of CGI causes easy heat transfer and gain to and from the outside environment. Therefore, the graph (Figure 3), of a single day i.e, 3rd of March 2017, between (11:00-14:00), shows that the top floor is comparatively hotter than ground floor during the day time.

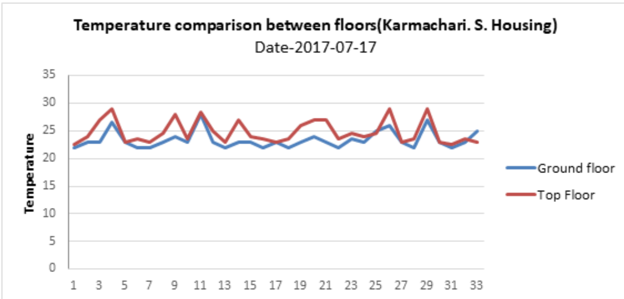

Figure 4: Temperature between floor in Karmachari Sanchayakosh Housing

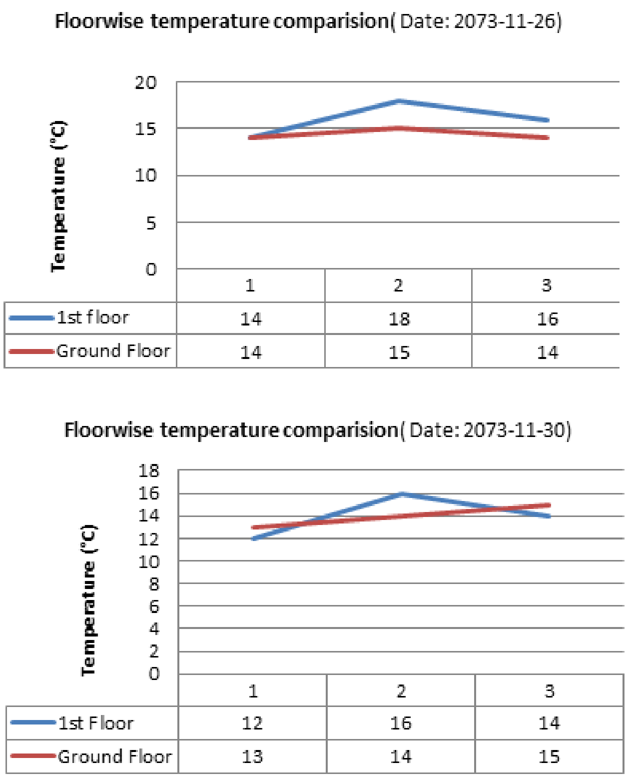

Figure 5: Comparative temperature graph between two floors for three different timing in Paliphal Housing

Similarly, the graph above (Figure 4) exhibits relatively higher indoor temperature in the first floor of Karmachari Sanchayakosh Housing. But the variation in temperature is not as high as that of Paliphal. This is because both the floors in Karmachari Sanchayakosh Housing are made up of precast concrete slab. But since, the first floor roof has exposure to the exterior environment, the heat loss and heat gain is high. Therefore, the top floor relatively showed a higher temperature at the time of survey July 17, 2017 between (10:00-14:00).

Apart from the temperature recording of a single day, temperature for a week from a single dwelling of Paliphal Housing was recorded at three different time of the day. The graph (Figure 5) plotted from the data shows that there is high fluctuation of temperature in the first floor in three different timings. This is due to the higher U- value of CGI and low time lag of CGI resulted in instant rise in indoor temperature during the day and instant fall during the night.

4.5 Economic Opportunity

To assess, economic opportunity around the neighbourhood of all the housings, the survey was based on the job opportunities available around the vicinity. The result of the survey can be illustrated from the chart (Figure 6). The job opportunity around Paliphal Housing and Samabesi-tole is low because of being located in residential zone and quite at a distance from the market place. However, the job opportunity around Sanchayakosh Housing, Pokhara is high because it is located in the city centre, which is a mixed land use zone.

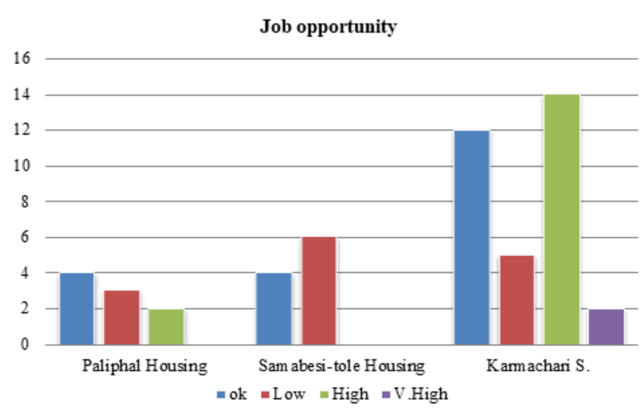

Figure 6: Job opportunity around the neighborhood

4.6 Accessibility

Accessibility is an important factor for sustainability of any projects. Need to travel long distances to get to their places of work daily increases the dependency on vehicles, and also increases the time spent, which in turn increases the resources used in fueling vehicles. This may not be affordable to the low income people.

More than 60 percentage of the occupants from Paliphal

Housing, Kirtipur traveled greater than 4 km to reach to their work place (Figure 7). Therefore, when interaction with the occupants in Paliphal Housing, they were not happy with the location with respect to the distance they had to travel every day for work. Similarly,more than 50 percent and more than 40 percent of occupant from Samabesi-tole and Karmachari Sanchayakosh Housing, Pokhara needed to travel 1-2 km to reach to work place, which is towards the market area, Pokhara. Their main commuting mode is motorcycle, walk and public bus and they found the housing at convenient location.

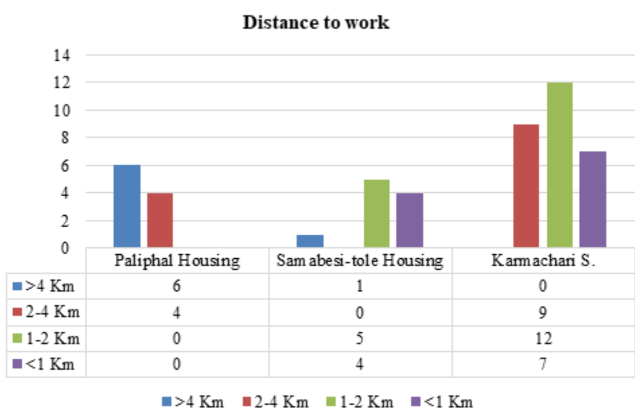

Figure 7: Distance to work from the housing

4.7 Size of Dwelling

The minimum area of a habitable room in Paliphal Housing is the smallest of all other cases. However,with average four people in a dwelling, the floor area per capita was computed to be close to that of Sambesi-tole Housing, i.e., 11 (Figure 4). The floor space per capita at the dwelling level for all the case study housings demonstrates that affordable housing is not sub-standard in this regard.

Table 4: Space calculation at household level

	Floor area(m^2)	Minimum area of a habitable room(m^2)	Average household size	Floor area per capita
Paliphal Housing	50	7.9	4.5	11.1
Samabesi-tole Housing	42	8.9	3.8	11.05
Karmachari S. Housing	98.5	-	3.7	26.6

The findings show that all case studies met the building standard of Kathmandu valley for minimum area of a habitable room to be 7 m^2 (for multiple room dwelling)[3] and also that of Indian standard for low cost housing which has set the minimum area of habitable room to be 6.5 m^2[4]. The majority of occupants from all the housings felt that the room sizes were optimum. But, few occupants from Paliphal Housing were unsatisfied with the size of the rooms and emphasized on the fact that the room could hardly fit a double bed.

5. Sustainable Design Strategy

Based on case study analysis, a set of strategies that should be taken into account when designing any affordable housing in hilly urban region of Nepal has been explained in the table(Refer to Table 5).

6. Material and Technology Recommendation for Indoor Thermal Comfort

To maintain indoor thermal comfort in a space by natural means, materials and technology in walls and roofs should be constructed such that it should have maximum time lag with low U value. The building materials for wall recommended for hilly urban region of Nepal is Hollow Concrete Block which has 1.89 W/m^2.C of U-value and large time lag. However, since the mass housing requires a huge quantity of building materials. There is also a scope of CSEB which can be locally made at site.

For a new construction, roofing technology recommended for hilly urban region of Nepal is RCC filler slab with again 4” hollow CSEB used as filler material. Filler slab technology is not a new thing. The construction process is to similar to construction of Reinforced Brick Concrete (RBC) slab. It is a low cost solution which is easy to install, operate and maintain. Moreover, filler slab is relevant for temperate climates where there is need of both winter heating as well as summer cooling. Filler slab also fulfills the need of a private terrace, which was also a major demand of occupants in Paliphal Housing, Kirtipur, which lacked private open space.

For already constructed roof, like CGI, simple interventions such as a soffit vent allows the roof to act as a ventilated roof which improves indoor thermal comfort. This could be coupled by providing insulated false ceiling Insulated false ceiling is a critical solution

Table 5: Sustainable design strategy for affordable housing in hilly urban areas of Nepal

Features	**Sustainable Design Strategy for Affordable Housing**
Density	The people in Nepal prefer to have their own individual house. According to CBS 2003, the percentage of single household residing in a house in overall Nepal is more than 90 percentage. From this data and the case study, it can be said that row housing is the best option of housing type. IS8888 has set the density (no of units per hectare) to range between 125-150 for metropolitan[4]. Therefore, no of units per hectare can go as high as 144 when the units are properly planned in a row and around open spaces as in Paliphal housing . Similarly population density in land area (hectare) can go as high as 600.
Passive solar design	For hilly region in Nepal, the design of dwellings needs to consider cold climate as it has longer winter. Orientation of dwellings needs to provide more sunlight penetration. It is better to orient the longer walls toward south. Similarly, the planning of the dwellings need to consider the natural wind flow of that area. To encourage natural air flow inside the room, cross ventilation is a good natural means.
Renewable energy technology	It is always good to integrate PV panels in design of sustainable affordable housing.
Energy efficient appliances	Low energy electricity bulbs like LED bulbs should be encouraged to use.
Building materials	When selecting walling and roofing materials, local availability, easy installation and maintenance, reasonable cost and thermal performance are the major criteria to consider. Therefore the choices can be limited to 8" thick hollow concrete block or 8" CSEB as walling materials and ventilated CGI roof with plastic bottle insulation or filler slab as roofing technology.
Water supply	All the households in housing need to have access to domestic water supply. According to a report by Joshi et al. (Joshi, 2003), the average domestic water consumption in the valley is about 94 lpcd (in 2003). The KUKL estimated water demand for the population located in its service areas assuming water consumption equals to 135 lpcd (Parmeshwar Udmale, 2016). From the case study findings the households whose average lpcd was lesser than 60 was unsatisfied with the water supply. Therefore as said by Joshi, the minimum water supply has to be around 135lpcd to meet the basic demand of domestic water supply. Water deficiency to certain extent can be met through rainwater harvesting. However the challenge would be to make it economically viable.
Ground water recharge	Use of pervious pavement or open joint blocks for streets can increase rain water percolation into the ground. In open areas, recharge pits can also help recharge ground water and water collection.
Solid waste management	Solid food waste can be collected to be recycled and use as feed for pigs. Also, other organic solid waste can be composted in portable compost bins to be used as compost in kitchen garden.
Liquid waste management	The grey water can be treated by passing it through reed plant bed before connecting it to the municipal sewerage.
Affordability	Monthly repayment of the dwelling units may not exceed 30% of household income.
Economic opportunity	The housing should be located such that there need to have optimum employment opportunity around the vicinity.
Accessibility	The housing location can be determined by how far one has to travel every day for work. The distance to work from the housing should be easily accessed by foot, bicycle or on public bus. From the case study, it was known that travelling greater than 4km to reach the work place was inconvenient to people. Therefore, the traveling distance for work is preferred to be lesser than 4km. Similarly, the travelling distance to primary school is preferred to be accessed on foot.
Proximity to facilities	Distance to common facilities like bus stop, groceries etc should be within walking distance. From the case studies, it was learnt that it is better if the distance could be within 500m.
Healthy indoor environment	Although the area of opening per floor area in all the case studies met the minimum Nepal's standard i.e., 1/10. But, the occupant's with 1/6 still felt that the light and ventilation was insufficient. Therefore it is recommended that the area of opening per floor area should at least be 1/6.
Housing diversity	It is recommended to have housing diversity so that it can cater the need of various occupants. None of the cases had the provision of renting the dwellings. Therefore one kind of diversity could be rental housing type, which can be financially affordable to those who find repaying difficult. Other diversity could be in number of bedrooms. This allows less initial cost or less monthly installment to small size households.
Safety	Housing structure and people safety need to be considered while planning and designing the housing. The housing structure as a whole should be safe from natural disasters like flood, landslide etc. and also people and their property needs to be safe from wild animals, theft etc.
Size of dwelling	The Asian countries have set the standards of per capita floor area to be around 6 sq.m [5]. Also from two different case studies, the per capita floor area has been computed to be 11sq.m., which was found to be moderate to the majority of occupant. Therefore, it is recommended that the per capita floor area could be a minimum of 11 sq.m.
Community participation	To encourage social bonding, presence of community groups in housing is encouraged. Also, for a housing to become socially acceptable and sustainable, community participation approach in design is recommended.
Adaptability	Incremental type of housing is merely recommended. There may be provision of internal modification however retaining the similarity of exterior look.
Open spaces	Well-defined open spaces like streets, gardens, parks and walkways, should be incorporated while designing affordable housing, which will give sense of a strong neighbourhood and will be a place of escape in case of emergency. Design should follow the minimum standard of open space for housing in Nepal.

Figure 8: Filler Slab with CSEB as filler materials

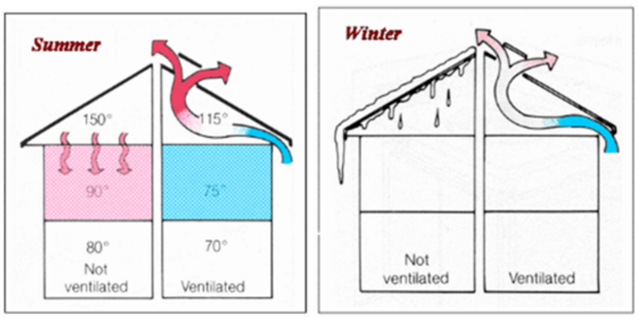

Figure 9: Working principle of ventilated roof

to thermal efficiency in affordable housing. The false ceiling traps air and ensures reduction of heat flow in or out of the house. In summer, the hot air in the attic is replaced by cool air. In winter the moist air in the attic is removed by cross ventilation of air (Figure 9).The false ceiling can be locally produced like the bamboo mat supported in bamboo.The low cost roof insulation technology as suggested by [6] could also be large sacks stuffed with empty plastic bottles placed above the mat false ceiling.

7. Conclusion and Recommendation

7.1 Conclusion

When analyzing all the case studies, it can be concluded that all the cases are economic sustainable in terms of repayment ability of the occupants and social capital. However, there are short-comes in case of environmental sustainability, specially in the use of building materials. Paliphal Housing, which practices composting of organic waste, has grey water treatment plant, harvests rain water and uses energy saving bulbs, however uses unsustainable walling and roofing materials creating thermally uncomfortable indoor space.

From the finding it can be concluded that in case of row housing, the choice of roofing material becomes important because unlike walls it is exposed to external heat and cold. A proper design of ventilated roof with low cost insulated bamboo mat false ceiling can help to maintain a comfortable indoor temperature.

7.2 Recommendation

Typically resettlement and affordable housing projects are conceived based on cost-benefit studies, often excluding the assessment of indirect social and environmental costs. Assuming that there is also an urgent need to improve the social and environmental condition of the inhabitants, such a study may be far more significant than a simple cost analysis. The findings in this research show that the actual average family size is approximately 3.7-4.5 persons per household. Hence, this suggests that the national standard should be focused on space per capita, rather than unit size.

In Nepal context, low-income settlements – especially in inner city areas – help support a number of urban functions, particularly the provision of food through street-vending, motorbike and taxi services, and other services in the informal economy. Therefore, enabling the lower-income groups to live in the inner city area is essential to the functioning of the urban economy, especially in the absence of affordable and efficient transport options. Therefore, designers of affordable housing must importantly include the connectivity of neighborhoods to the city centre. Also, public participation based programme for encouraging rain water harvesting and grey water treatment plant should be initiated so as to assure water security and sustainable waste management at household level.

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