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A Housing Morphology: For the case of proposed Panchkhal Smart City

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Abstract

This study analyses the housing sector of the proposed Panchkhal smart city, on the basis of energy efficiency and cost effectiveness. Firstly, the user's perspective towards energy efficient house is analysed through questionnaire survey. Secondly, it studies energy efficient housing for the proposed Panchkhal smart city through exploratory research. During the study, a bioclimatic chart for Panchkhal was developed which shows thermal comfort range of 19°C to 28°C. Four scenarios of a typical single family detached house are analysed qualitatively and quantitatively in terms of indoor temperature and heating cooling load. Base case scenario I, a typical contemporary housing is improvised into scenario II with passive solar design in terms of orientation, layout and openings; scenario III with passive solar design also having thermal insulating materials; and scenario IV with an addition of solar home system. It is analysed that the indoor temperature of coldest day increases up to 0.68°C by passive design without thermal insulating materials and up to 7.5°C by passive design with thermal insulating materials while the indoor temperature of hottest day decreases up to 2.5°C by passive design without thermal insulating materials and up to 7°C by passive design with thermal insulating materials. The annual heating cooling load for scenario I is 1299.28 kWh/yr which decreases to 1116 kWh/year in scenario II and further decreases to 353.62 kWh/yr in scenario III and IV. Thirdly, cost effectiveness is analysed in terms of NPV of cost and annual saving for energy. It is analysed that the NPV of cost of scenario I is more than scenario II by 1.75%, more than scenario III by 2.62% and more than scenario IV by 4.32%.

Keywords

Energy efficient housing – Smart city –Psychometric chart – Indoor temperature – Heating cooling load – Net Present Value – Annual Saving

1. Introduction

1.1 Background

In Nepal, with new municipalities added in 2014 and 2015, the urban population now accounts for 40% [1]. However, the rural migrants in Kathmandu valley are creating intensified demands of energy consuming services like housing. In this context, the concept of smart city is being developed. Focusing on housing sector, the proposed smart cities of Nepal should be able to plan and design residential sectors that would be disaster resilient, eco-friendly and energy efficient [2]. Energy efficient homes includes homes that are designed to reduce the overall environmental impact during and after construction in such a way that we can meet the needs of the present without compromising the ability of future generations to meet their own needs. This can be accomplished by efficiently using resources like energy and providing energy savings. Moreover, the household sector in Nepal consumes 87% of total energy [3] as shown in Figure 1 which has been addressed in this study.

1.2 The Study Area

The Civil Group of Companies has introduced the concept of smart city at Panchkhal Municipality of Kavrepalanchowk district, as one of the most feasible city especially because of nearer proximity to Kathmandu (44.6 km). It has proposed housing

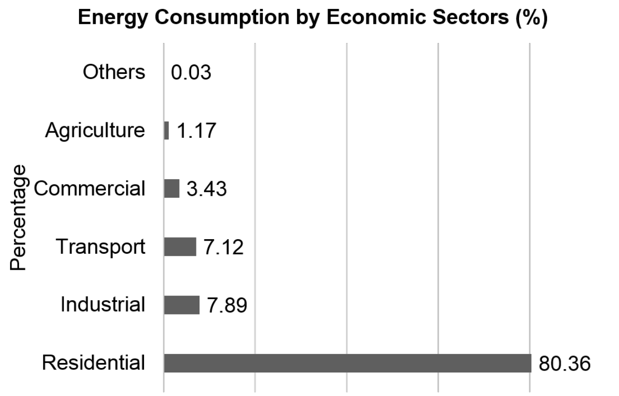

Figure 1: Energy Consumption Situation by fuel type in Nepal 2011/2012 (Source: WECS, 2014)

complexes for the proposed Panchkhal smart city.

1.3 Objective of Study

General Objective

- To study housing sector for the proposed Panchkhal smart city in terms of energy efficiency and cost effectiveness.

Specific Objectives

- To study the prospect of energy efficient homes from user's perspective.
- To study and analyse energy efficient housing for the proposed Panchkhal smart city, in terms of indoor temperature and heating/cooling load.
- To study cost effectiveness of the energy efficient housing in terms of Net Present Value (NPV) of cost and annual saving.

1.4 Limitation of Study

This research based on housing morphology for the proposed Panchkhal smart city is only limited to the housing sector of the proposed Panchkhal smart city and doesn't focus on ICT, infrastructure and services. The research is limited to the residential sector, focusing only on single family detached house and doesn't include multifamily housings.The economic analysis is done only in terms energy consumption and for only the detached single family housing, forecasting to the year 2027.

2. Literature Review

A range of renewable energy in cities can lead to smart city. Both solar thermal energy and photovoltaic (PV) are modular technologies that can be integrated in residential buildings [4]. Five design principles have been developed by UN Habitat Nepal in their project – "Promoting Sustainable Housing in Nepal" in 2014 which includes green building materials, passive solar design, energy efficiency, water conservation and waste management [5]. Since Panchkhal has a warm and humid climate, the design principles are studied in the context of warm and humid climate.

The general principles of passive design for warm and humid climate are minimization of the high day temperature, avoidance of direct exposure of facades to solar radiations, reduction in the humidity levels and continuous air circulation to reduce heat. Obaidin (2014) developed a very clear framework for the strategies of passive cooling, which generally fall into three categories: i.Solar and Heat Protection ii.Heat Modulation or Amortization Technique iii.Heat Dissipation Technique. Energy efficiency can be improved with smart management and operation like actuators, thermostat and sensors. [6]

Status quo of Cities in warm and humid climate have been studied like Auroville Town Planning of India, Anupama Kundu Residence at Auroville, India and Solar Settlement at Schlierberg, Freiburg, Germany. Similarly, energy efficient houses of Kathmandu like Mato Ghar at Budhanilkantha and residence of Architect Ujjwal M. Shakya at Maharajgunj were studied.

3. Methodology

This research on the housing morphology for the case of proposed Panchkhal smart city is based on an exploratory research methodology. Through intensive literature reviews, it is known that a smart city includes smart buildings which are generally focused on energy efficiency and cost effectiveness. The case Panchkhal is studied on the basis of the existing scenario of houses and climatic context. After that, a survey is conducted to validate the research through the user's preference towards energy efficient house in Nepal. After achieving the validity through the survey, study of design of such houses for proposed Panchkhal smart city was conducted on the basis of literature reviews which was later simulated in Autodesk Ecotect software for quantitative justifications on energy efficiency and cost effectiveness.

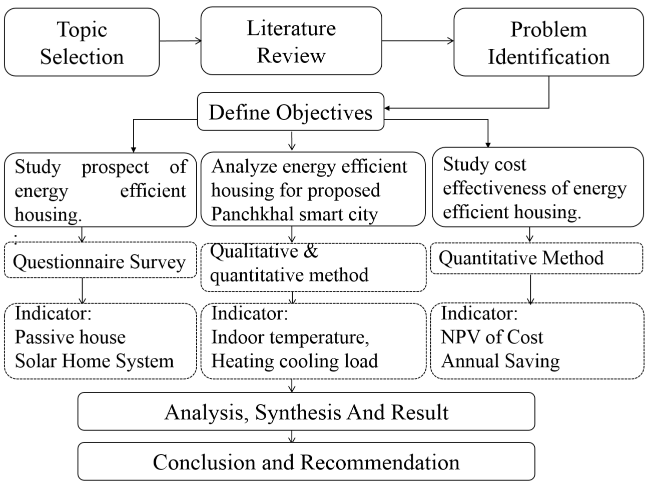

Figure 2: Conceptual Framework of Study

3.1 Method for study of prospect of energy efficient house from user's perspective

For a population between 10,000 and 25,000, a sample size of 192 to 195 is recommended, giving results with a 7% margin of error at the 95% level of confidence [7]. Since the number of household units in the proposed Panchkhal smart city is 20,000, this reference was used for deciding on the number of samples. A pilot test was done to correct the questionnaire if required. Then the corrected questionnaire was distributed among 260 respondents. 32 questionnaires were not returned and 23 of the returned questionnaire were unsuitable to include. So, 205 questionnaires were selected for analysis.

3.2 Method for analysis of indoor temperature, heating and cooling load

Four scenarios for a typical single family house is developed placing them in their respective neighbourhood context as shown in Figure 3.

Base case scenario I, a typical contemporary housing is improvised into scenario II with passive solar design in terms of orientation of rooms, building form and openings; scenario III with passive solar design also having thermal insulating materials; and scenario IV

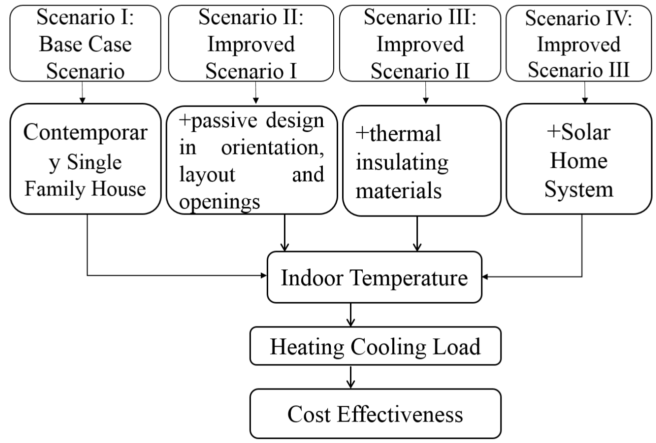

Figure 3: Scenarios for Analysis

with an addition of solar home system. The scenarios are initially developed qualitatively on the basis of literature reviews and case studies, and are later quantitatively simulated in Autodesk Ecotect in terms of indoor temperature and the relative heating cooling load required.

3.3 Method for economic analysis of the housing morphology

Economic analysis has been conducted for the above mentioned scenarios in terms of NPV of cost and annual savings using the following procedures.

- Calculation of energy consumption for heating and cooling using Ecotect software.
- Calculation of energy consumption on cooking, appliances, lighting using primary data.
- Secondary data collection for inflation rate of electricity, appliances, solar home system, electronic goods, discount rates and so on.
- Calculation of energy consumption and cost is done for the life span of house for each scenario i.e. 40 years which includes,
  - Initial Capital Cost (NRs) including construction, design and initial equipment cost.
  - Annual energy consumption (kWh) and Annual Cost (NRs)

– Future Cost calculated by projecting the annual cost to base year 2027 using inflation rates and to the 40 years life span of building.

- NPV of Cost for 40 years is calculated as the sum of the initial and the future cost.
- Annual saving in a scenario calculated by deducting the NPV of one scenario to the NPV of another scenario.

4. Data Collection

Climatic data of Panchkhal for temperature, humidity and rainfall are collected from DHM, Nagpokhari.

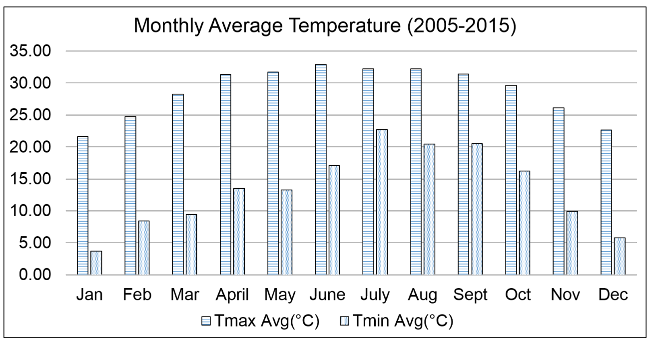

Figure 4: Temperature Data of Panchkhal (2005-2015)(Source:DHM,2015)

Primary data collection was done where field survey was conducted at Panchkhal. Majhdihi of Ward No. 2 lies in the area allocated for low density housing in the proposed smart city. So , the particular location was selected for sampling and field survey.

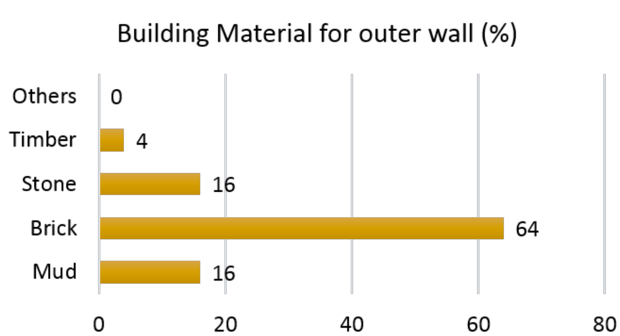

Figure 5: Building material used for outer wall at Panchkhal

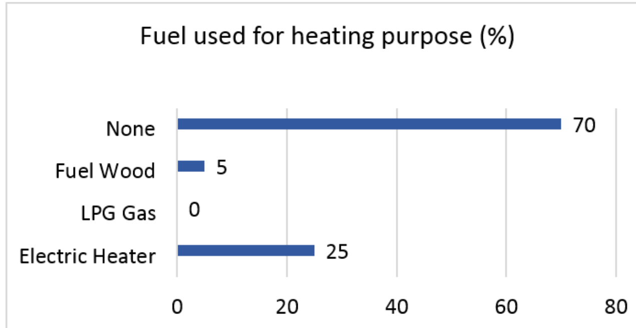

Figure 6: Fuel used for heating purpose at Panchkhal

For the economic analysis of the housing morphology, secondary data is collected on various aspects of energy sector.

- NRB discount rate of 10% referred by taking an average of ten years from 2006 to 2016.
- Replacement cost of equipment calculated by taking the annual 5% increase in dollar value taking the data from 2005 as Rs 70/- to 2015 as Rs 109/- (currency, 2016)
- Inflation rate of SHS in yearly decrement rate of 6.5% per year[8].
- Inflation rate of construction materials considered to be 6.3% per year calculated from the annual percentage change of 2008 to 2015 [9].
- Per unit rate of Electricity taken as Rs 12/- per unit, considering the amount of electrical units consumption and ampere [10].
- Yearly increment rate of electricity has been calculated as 3.5% per year ([10].

5. Analysis, Findings and Results

5.1 Validity of Research from user's perspective towards energy efficient design

The survey conducted on user's perspective towards energy efficient design shows validity to the research as per the result shown in Table 1.

Table 1: Result of survey based on user's perspective towards energy efficient house

Question Asked	Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
I prefer to live in a house that doesn't require appliances for heating and cooling, by achieving its own thermal comfort.	7.3 %	2.4 %	4.4 %	54.6%	31.2%
I would be willing to pay 15%-30% more in initial cost to prevent using appliances for heating and cooling that will also reduce operating cost of electricity, appliances and fuel in future.	-	2.4%	19.5%	51.2%	26.8%
I would be willing to pay NRs 500,000/- to NRs 1,000,000/- more for a home with solar home system (with photovoltaic panels, inverter, battery, thermostat) than a home without solar home system.	4.2%	4.2%	31.9 %	53%	6.7%

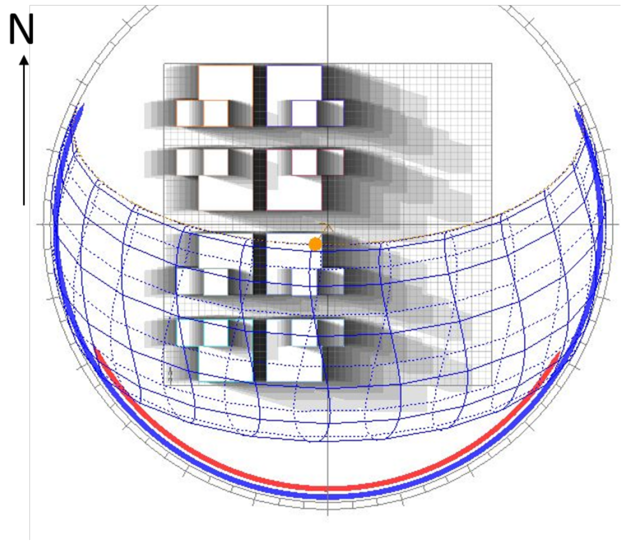

Figure 8: Portion of the typical master plan of base case scenario I

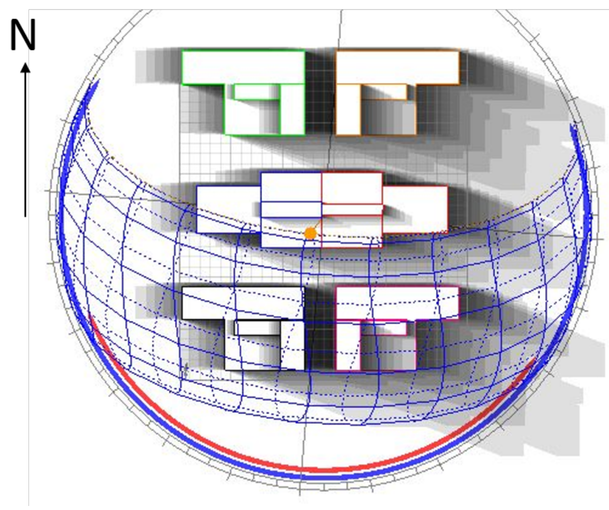

Figure 9: Portion of climate responsive masterplan of Scenario II/III/IV

5.2 Development of Psychometric Chart

During the study, the psychometric chart for Panchkhal has been developed as shown in Figure 7. Through the chart, it is known that most of the months are warm and humid. Thermal comfort in winter is between 19°C to 24°C and thermal comfort in summer is in between 24°C to 28°C. Most of the months except January and February require air movement. Almost all months of winter can have passive solar heating. HMNV is suitable from April to September.

5.3 Scenario Analysis

The analysis of the housing morphology for the proposed Panchkhal Smart city has been done on the basis of different scenarios placing them in their respective neighbourhood context as shown in Figure 8, and 9.

5.3.1 Comparison of Indoor Temperature

The heating and cooling load has been calculated for the three scenarios as per the indoor temperature from Autodesk Ecotect. Besides, orientation, layout and openings, the scenarios have been interpreted on the u-value of building materials used as shown in Table 2.

Finally, comparison of indoor temperature for the rooms of the house has been analyzed. Living room, master bedroom, bedroom, kitchen and dining have been placed

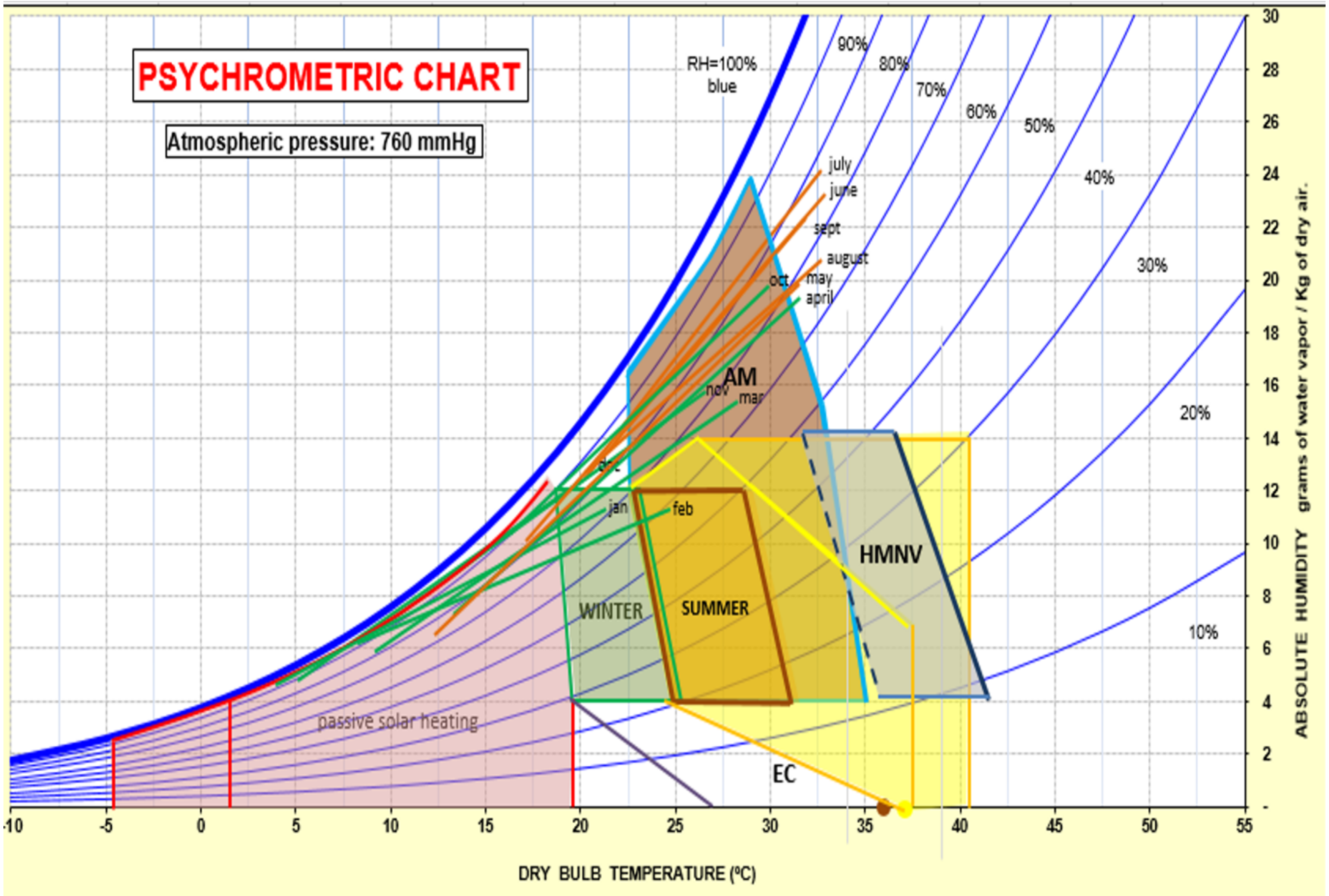

Figure 7: Psychometric Chart developed for Panchkhal

Table 2: U-value of building materials used for the scenarios

Building Component	Scenario I		Scenario II/III/IV	
	Building Material	U-Value (W/m2 K)	Building Material	U-Value (W/m2 K)
Exterior Wall	Burnt Brick (230x110x55) mm in concrete mortar & 12 mm cement plaster	1.98 W/m2 K	Double CSEB 254X127X76) mm with 50mm air cavity and 12 mm lime plaster	1.09 W/ m2 K
Interior Wall	Half burnt brick (110x230x55), in concrete mortar & cement plaster	2.25 W/m2 K	127 mm thk CSEB wall with 12 mm lime plaster on both sides	1.87 W/m2 K
Floor	110 mm concrete slab	4.89 W/m2K	110 mm concrete slab with timber floor suspended on wooden joists with air cavity	0.56 W/m2K
Roof	110 mm conc slab with cement tile	3.033 W/m2K	Green Roof Double roof with cavity	0.32 W/m2K
Window	Single Glazed window	5 W/m2K	Double glazed window	3.06 W/m2K

in thermal comfort space for indoor temperature analysis.

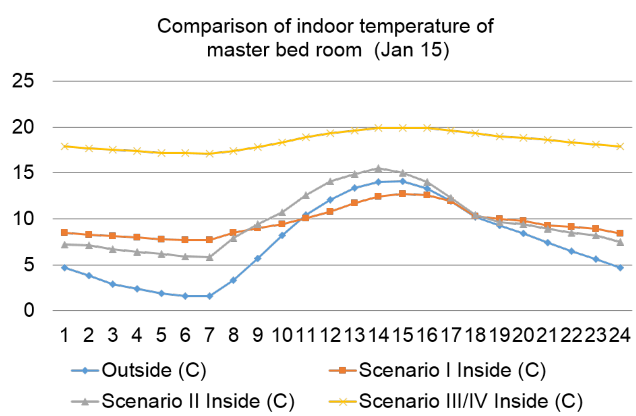

Figure 10: Indoor temperature of Master Bedroom in coldest day

The analysis of all rooms shows that the average winter

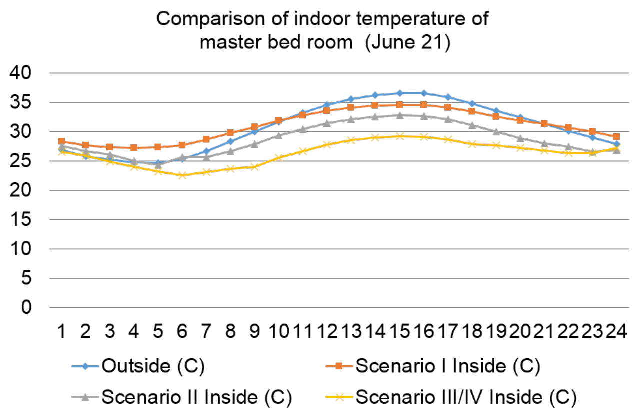

Figure 11: Indoor temperature of Master Bedroom in hottest day

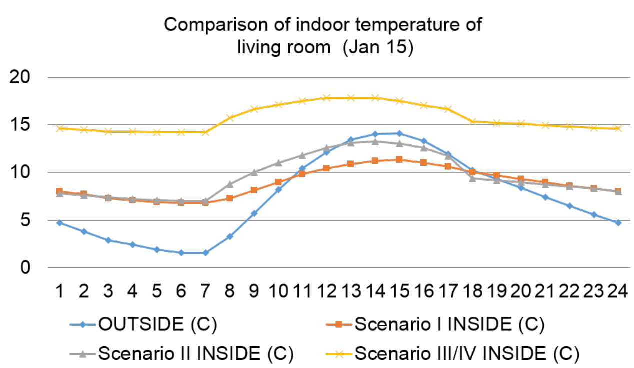

Figure 12: Indoor temperature of Living room in coldest day

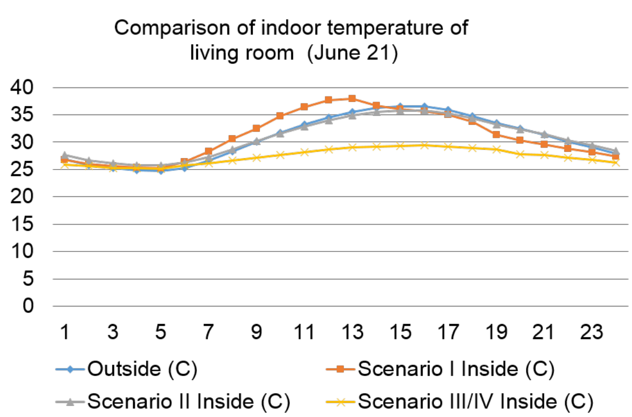

Figure 13: Indoor temperature of Living room in hottest day

temperature on January 15 increases upto 0.68°C in scenario II i.e. passive solar design without using thermal insulating materials and increases up to 7.5°C in scenario III i.e. passive solar design with thermal insulating materials. Similarly, the average summer temperature on June 21 decreases up to 2.5°C in scenario II i.e. passive solar design without using thermal insulating materials and decreases up to 7°C in scenario III i.e. passive solar design with thermal insulating materials.

5.3.2 Comparison of Heating Cooling Load

The heating and cooling load has been calculated for the three scenarios as per the indoor temperature derived for all rooms from Autodesk Ecotect.

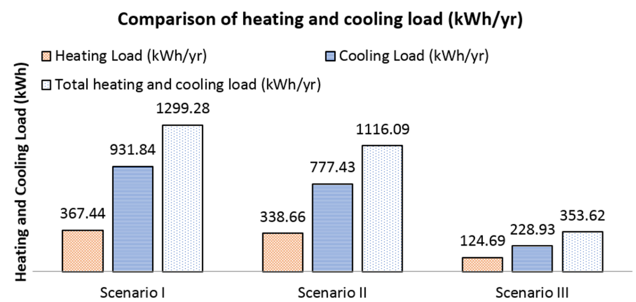

Figure 14: Comparison of heating and cooling load (kWh/yr)

5.3.3 Comparison of Cost Effectiveness

The Figure 16 shows that the NPV is lowest in scenario IV because of the use of solar PV which is in yearly decrement rate of 6.5% [8] and less annual electricity bill which is in yearly increment rate of 3.5% per year [10].

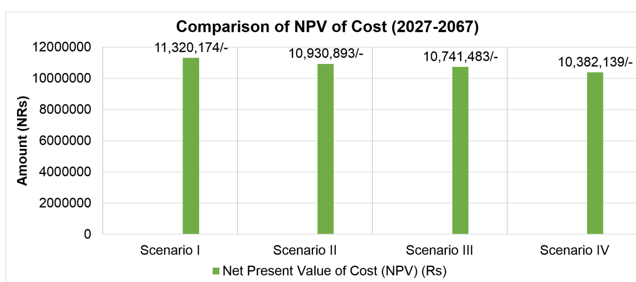

Figure 15: Comparison of NPV of Cost (2027-2067)

The analysis shown in Figure 16 on annual saving shows that a passive house with active solar energy technology for electricity can provide more annual saving than a passive house without active solar technology from 23.9% to 41.9%.

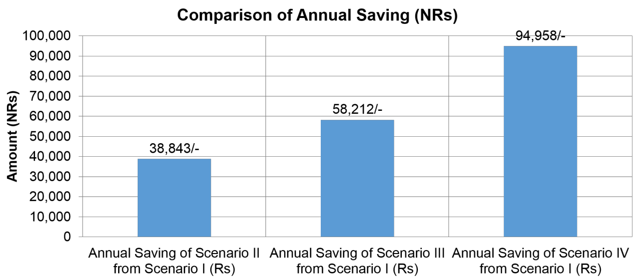

Figure 16: Comparison of Annual Saving (NRs)

5.4 Implementation in Master Plan

The finding of the study shows that it is preferable to orient the longitudinal sides of the residential plots towards North-South in the master plan of the proposed Panchkhal smart city .

5.4.1 Formulation of Bye-Laws

The new bye-laws of the proposed Panchkhal smart city shall be formulated as per the results of this analysis. Bye-laws that shall be formulated for the detached house of residential sector are,

- Longitudinal sides of house should face North and South.
- There should be a setback of at least 2.5 m towards South.
- Each house should install at least 1 kW of solar home system and sell the extra electricity to smart metering system.
- Each house should have a central inner courtyard for wind stack effect with void.

6. Conclusion and Recommendation

6.1 Conclusion

Through the questionnaire survey, it was known that 54.6% agree and 31.2% strongly agree to live in a house that doesn't require appliances for heating and cooling, by achieving its own thermal comfort. Similarly, 53% are willing to pay extra investment for solar home system. The result showed positive preference towards energy efficient housing from potential user's perspective. Similarly, through the climatic analysis, it was known that Panchkhal has a warm and humid climate with a thermal comfort range of 19°C to 24°C in winter and 24°C to 28°C in summer. Average winter temperature can increase up to 0.68°C in passive solar design without using thermal insulating materials and up to 7.5°C in passive solar design with thermal insulating materials. Average summer temperature can decrease from 2.5°C in passive solar design without thermal insulating materials and up to 7°C in passive solar design with thermal insulating materials. Heating and Cooling Load in contemporary house can decrease to 7.76% in passive solar design and further decreases to 58% in passive solar design with thermal insulating materials. NPV of cost of a typical contemporary house is more than passive house without thermal insulating materials by 1.75%, more than passive house with thermal insulating materials by 2.62% and more than thermally insulated passive house with active solar home system by 4.32%. In this manner, scenario III/IV proves to be the best in terms of energy efficiency and scenario IV proves to be the best in terms of cost effectiveness.

With qualitative and quantitative analysis based on indoor temperature, heating cooling load and cost effectiveness of energy use, this research justifies that an energy efficient house would harmonize with the proposed Panchkhal smart city to act smart.

6.2 Recommendation

Few recommendations from the thesis work are

- The chart developed for Panchkhal shall guide planners and architects to make general decisions to develop climate responsive and energy efficient building designs.
- The scenarios presented in this research can be applied to different locations and climate. efficiency and cost effectiveness.
- Any new idea if implemented in a mass scale in the form of housing would be more effective to implement and shall gain more trust from the entire community.

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