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Urge of New Town: Energy Resilient Urban Morphology

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Abstract
Energy consumption in buildings is significantly affected by urban morphology. Urban morphology has a great effect on thermal performance of the buildings. Residential sector is considered highest consumer of energy in the world which is why studies that deals with reducing energy consumption in residential buildings are very important. This research is an attempt to study thermal performance and its impact on thermal comfort of residential buildings and thereby produce urban energy planning guidelines as an outcome for the context of Kathmandu. This study intakes three residential areas with distinct urban morphology characteristics, which are Bode, Libali and Srija-nanagar. The research attempts to see the effect of urban form, geometry, density and orientation on energy consumption of residential buildings. The research is carried out using the analytical approach by using computer program ECOTECT. The research aims to reach to the best possible configurations which presents the high thermal performance in order to use it in residential buildings in the Kathmandu valley. The results indicate significant thermal effects due to urban form, urban geometry, urban density and orientation. In Kathmandu valley, courtyard type housing is preferred and its orientation is found to be 0 degree which gives the best thermal performance in the residential units. Square buildings were found to be most appropriate in terms of energy efficiency in heating as well as cooling loads. Row house was found to be best followed by courtyard type. Furthermore, urban layout with minimum spacing ratio and maximum aspect ratio was found to be energy efficient in the case of E-W street orientation whereas spacing ratio maximum and aspect ratio minimum was found to be energy efficient in the case of N-S street orientation.

Keywords
Urban Morphology, Energy efficiency, Residential buildings, ECOTECT, Kathmandu Valley

1. Introduction

Urban morphology refers to the arrangement and spacing of urban elements such as buildings, streets and open spaces [1] and 'efficiency' means achieving maximum productivity with minimum wasted effort or expense.

Urban morphology has a direct linkage with the space heating/cooling energy demands. According to Adolphe, layout of city plays a major role in the energy consumption in the building sector of the city [2]. Similarly, Michael Doherty states that "There is relationship between density, urban morphology and form and energy consumption of the city" [3].

Defining systematic urban morphology is only possible at planning phase of a new town which can prove to be very energy efficient in terms of space heating/cooling in long run. New Town concept is a strategic response to emerging Megacities that faces fast population growth in cities and there are proposal by the government to plan new towns in the periphery of Kathmandu Valley. Unfortunately, there are no energy planning guidelines for Kathmandu, which can be followed to ensure energy efficiency and therefore, this paper aims to generate urban energy planning guidelines for residential sector of Kathmandu valley at neighbourhood level.

2. Objectives of the study

General objectives:

To explore the optimal urban morphology of residential zone at neighbourhood level of proposed new town in order to ensure energy efficiency in buildings and thermal comfort to achieve energy efficient residential neighbourhood.

Specific objectives:

- To identify and compare energy loads of present urban morphologies of residential units
- To produce an optimized model by changing parameters of urban form, urban geometry and urban density for residential unit with computer simulation software called ECOTECT
- To define urban energy planning guidelines for creating energy efficient urban residential neighborhoods

3. Methodology

This study is an explorative research to explore appropriate urban morphological parameters to upgrade energy efficiency at neighbourhood level of residential sector. It is a bottom up approach to develop energy planning guidelines.

The study is categorized into four parts, first part comprises of literature review, data collection and field observation which is followed by second phase where parameters of urban morphology is identified and analyzed in software ECOTECT. It calculates heating and cooling loads for models and analyze effects of occupancy, internal gains, infiltration, and equipment (Autodesk Ecotect Analysis, 2010). And simultaneously, questionnaire survey was carried out.

Energy consumption for three cases Bode, Libali and Srijananagar is calculated and also the effects of urban morphological parameters on spacing heating/cooling demand are assessed. Energy consumption is calculated in ECOTECT by having given the climate of Kathmandu in '.wea' file and thermal comfort band for Kathmandu so that realistic results can be envisaged.

discussion where results from the field data as well as results from ECOTECT are analyzed and discussed. Phase four defines the urban energy planning guidelines suitable for Kathmandu for residential units applicable at neighbourhood level.

4. Limitations of the study

- This study considers residential sector of proposed new town along Manohara River
- The study is conducted at neighbourhood level of residential unit.
- Environmental variables (air temperature and solar radiation) contributing to the thermal comfort are considered. However, individual variables such as metabolic activity and clothing are not taken into account
- Thermal analysis is considered but wind analysis and daylighting analysis are not considered in this study

Problem statement

Kathmandu is undergoing haphazard urbanization. Unplanned urban development in the Kathmandu Valley has led to rapid and uncontrolled sprawl; irregular, substandard, and inaccessible housing development; loss of open space, and decreased livability. The rate of influx of people is risen day by day. With growing number of people, energy demand is also expected to rise. People are expected to face many problems in absence of fulfillment of energy demand. These problems faced by people have to be addressed appropriately.

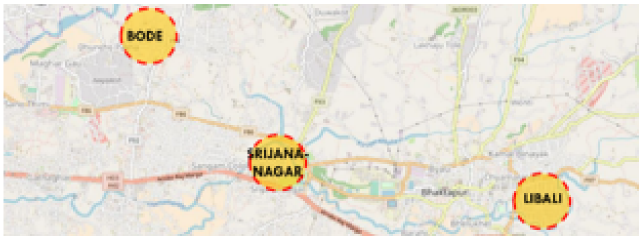
5. Rationale

Due to unplanned settlement and unmanaged urbanization, life in the city area is degrading [4]. Thus, to avoid these impacts which are occurring due to high population influx in the core city area, development of new towns in the vicinity of core area can be a solution.

Additionally, appropriate planning of urban morphology can give additional benefits in terms of saving space heating/cooling energy demand and also by providing comfortable living conditions inside the house. Thus, this study envisage to address the problems of haphazard urbanization by creating guidelines to ensure higher comfort level inside buildings and lowering the space heating/cooling energy loads.

Furthermore, this study addresses the gap of literature. Studies related to energy in buildings in context of Nepal, limited to building scale and does not reflect on the relation of energy and urban morphology. Also, there is lack of model which ensures energy resiliency in the residential sector at neighbourhood scale. All these arguments presents the need of this study.

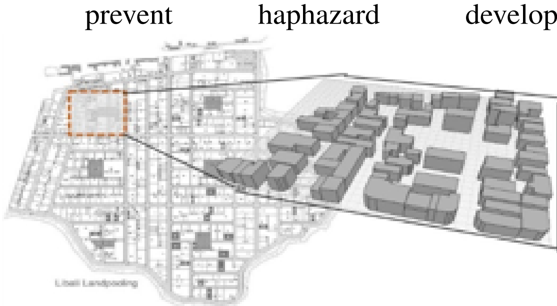
6. Case Studies

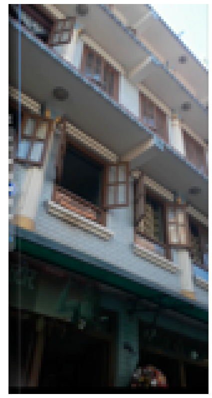


To attain the goal of proposing urban energy planning guidelines, it is important to understand he context. Since, the first new town has been proposed along Manohara Corridor, three sites were selected in order to study the present urban morphologies of residential sector present at the peripheral areas of proposed site.

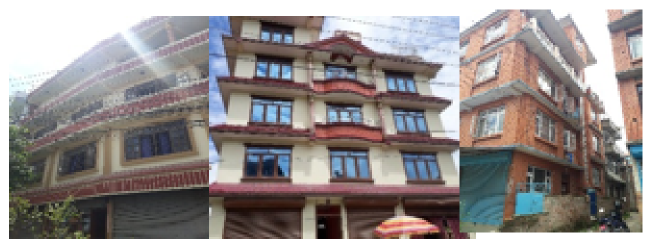
The first case taken is Bode, as it is the traditional settlement which has emerged over time reflecting the expertise of ancestors. Literature also supports the fact that traditional settlement planning is very energy efficient [5] .

Another site is Libali, which is a land-pooled area which is a prime principle followed for planning. Libali land pooling project is located at ward number 1 and 2 of Bhaktapur municipality. This project was formulated to prevent haphazard development.





The third site taken is Srijana-nagar, which is a haphazard settlement without any planning. By taking these three drastic cases in terms of urban morphology, the effect on energy consumption can be clearly witnessed.



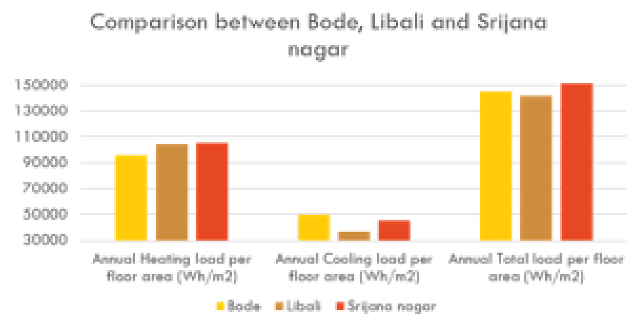
In each case, land area of 100m x 100m is taken. Annual space heating/cooling energy loads of all the buildings are then calculated in ECOTECT in per m2 of built up area so that they are comparable and the results are then discussed.

7. Results and findings

The results of study are categorized into two phases. The first one is comparison between Bode, Libali and Srijananagar in terms of annual heating/cooling loads when all the buildings maintain thermal comfort band.

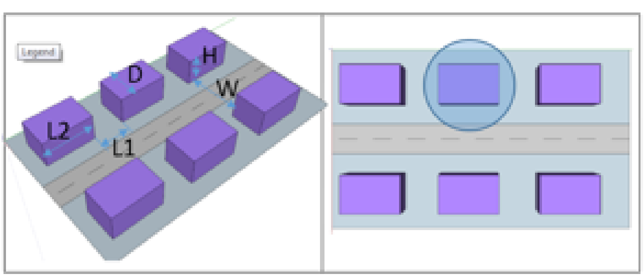
The second phase is comprised of parametric study which incorporated studying the impact of Urban form (Typology), Urban Geometry (Depth to length ratio of building, Spacing ratio, Aspect ratio and Orientation) and Urban Density (FAR). By studying these urban parameters and their impact on energy consumption, points which suits the climate of Kathmandu can be put forward as guidelines.

7.1 Phase I comparison of three cases in terms of space heating/cooling energy loads



The graph above shows that Libali land pooled area has the least annual total load as compared to the other two. However, Bode has the least annual heating load amongst all three. This proves that Bode is good in terms of heating load. Bode stands second in terms of total annual loads whereas Srijana nagar has the highest total annual loads in its account.

7.2 Phase II Parametric study of various Parameters

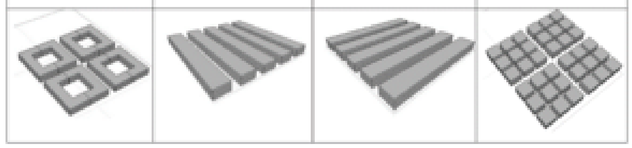


In the parametric study, a set of six buildings are taken as a cluster amongst which, the effect on centered buildings is only assessed as shown in the picture above.

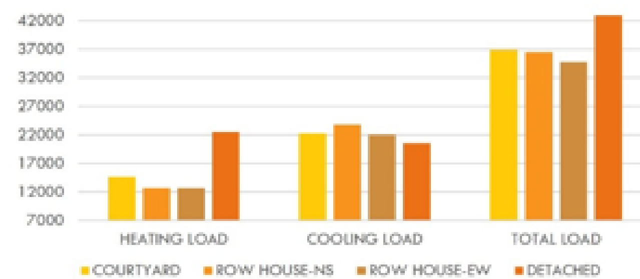
7.2.1 Effect of Urban Form (Typology)

Mainly four typologies are considered, Courtyard, Row type in EW orientation, Row type in NS orientation and detached type. The plot area, built up area and floor area for all the cases have been considered same.

Typology			
Courtyard Typology	Row type - NS	Row type - EW	Detached Typology



As the graph suggests, row houses are the best and detached houses are the worst in terms of total annual energy loads. Row houses are followed by courtyard type houses. Among row houses, the ones which are oriented EW street orientation act better than the ones which have street orientation along NS.



This may be due to the fact that heat loss is maximum in the detached houses than in any other configuration. When buildings are constructed adjacent to each other, a good amount of heat is conserved due to low heat loss, which is very valuable and beneficial in winter season. Also, shades that are created on the surfaces of adjacent buildings have beneficial impact on cooling loads.

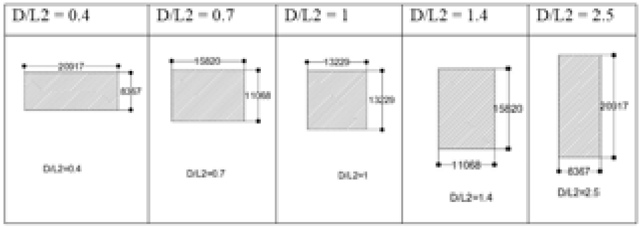
7.2.2 Effect of Urban Geometry (Orientation, Depth to length Ratio, Spacing Ratio and Aspect Ratio)

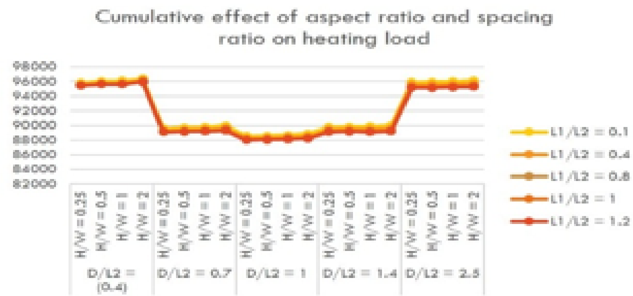
Shape	Depth to length ratio (D/L2)	Spacing ratio (L1/L2)	Aspect ratio (H/W)	Street Orientation
Rectangle and Square	0.4, 0.7, 1, 1.4, 2.5	0.1, 0.2, 0.4, 0.8, 1.2.	0.25, 0.5, 1 and 2.	E-W and N-S

As mentioned in the table above, urban parameters which are studied in parametric study are depth to length ratio, spacing ratio, aspect ratio and orientation and their impact in space heating/cooling energy demand are assessed.

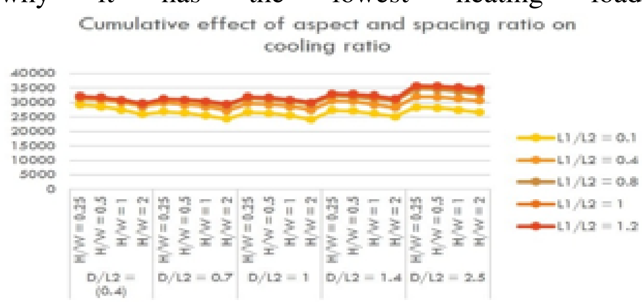
a. Effect of Depth to Length ratio of building There are five depth to length ratio which are considered, D/L2=0.4, D/L2=0.7, D/L2=1, D/L2=1.4, D/L2=2.5

which are taken in increasing order.





As the graph suggests, the heating is lowest when the D/L2 = 1 which is a square. It is because energy is related to surface to volume ratio. Energy load decreases with the decrease in surface to volume ratio. Square has the least surface to volume ratio which is why it has the lowest heating load.



Cooling load on the other hand can be seen to be changing with the aspect and spacing ration. The sensitivity of the cooling load increases with the increasing building ratio. Hence, if we see the combinations of heating and cooling load it can be concluded that building ratio 1 has the minimum energy consumption. Hence, square shape is preferred for Kathmandu Valley.

b. Effect of Spacing ratio Heating loads decreases with increasing spacing ratio. This is because south and east surfaces which traps sunlight are exposed with higher spacing ratio.

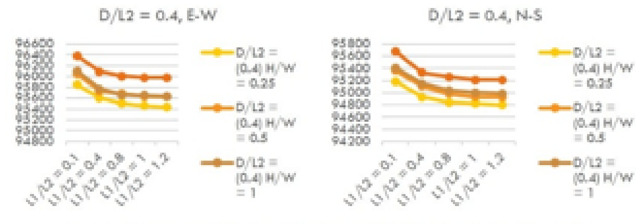


Figure 74: Effect of Spacing ratio on heating load in E-W and N-S, when D/L2 = 0.4

Cooling load increases with the increasing spacing ratio as there is more heat gain with the exposed surface when sunlight strikes the surface.

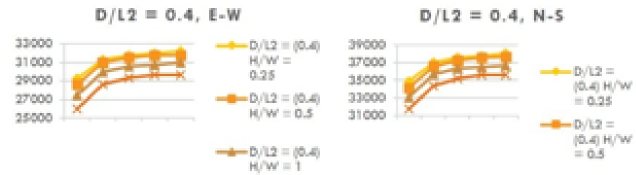


Figure 76: Effect of Spacing ratio on cooling load in E-W and N-S, when D/L2 = 0.4

c. Effect of Aspect ratio

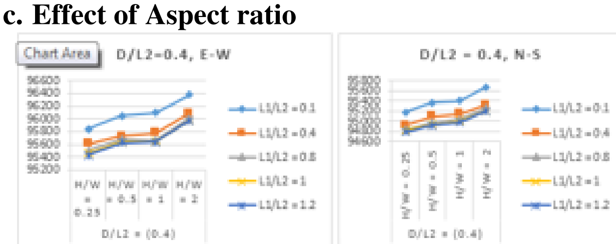


Figure 79: Effect of Aspect ratio on heating load in E-W and N-S, when D/L2 = 0.4

Heating loads increases with increasing aspect ratio. This is because south and east surfaces which traps sunlight gets shaded by the shadow of adjacent building.

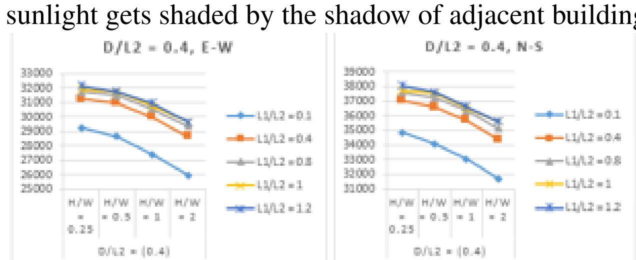


Figure 82: Effect of Aspect ratio on c Chart Area E-W and N-S, when D/L2 = 0.4

Cooling load whereas decreases with the increase of aspect ratio. The shaded portion of buildings becomes cooler in absence of receiving heat from the sun.

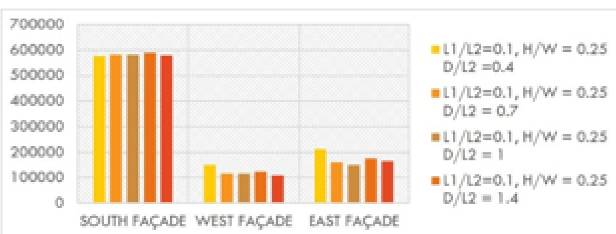
Summary chart on spacing and Aspect ratio

	Effect of Spacing ratio	Effect of aspect ratio
Effect on heating load	Decreases with increase in spacing ratio	Increases with increase in aspect ratio
Effect on cooling load	Increases with increase in spacing ratio	Decreases with increase in aspect ratio

The above mentioned figures illustrates that heating load can be the lowest by having least spacing ratio and highest aspect ratio. However, if the solar potential has to be harnessed, it can help in fulfilling heating load requirement. Thus, a right balance between lowest space heating/cooling load requirement and highest solar potential has to be found out.

Solar potential for various facades

South façade	249% more solar potential than east facade
West façade	Base value
East façade	41.48% more solar potential than west facade



It can be concluded that south façade receives the highest sunlight and has the maximum solar potential.

d. Effect on orientation

Building width to length ratio	Building orientation
0.4, 0.7 & 1	0°, 30°, 60°, 90°, 120°, 150°, 180°

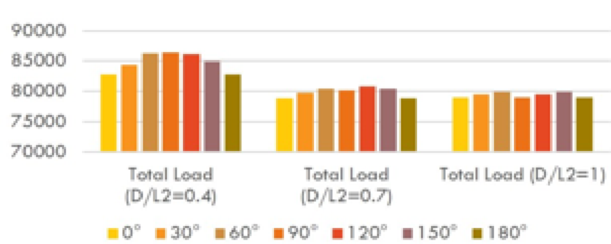
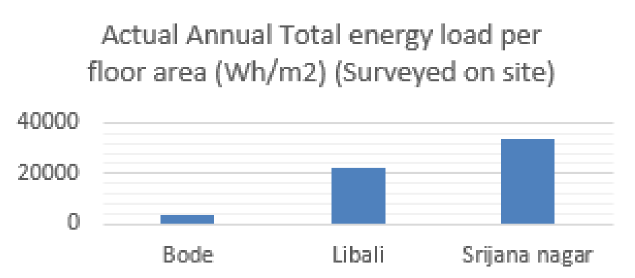


Figure 64: Effect on total load for various width to length ratio, Source: Author

There are six orientation taken for study which are 0, 30, 60, 90, 120 and 150.

Total load varies with orientation and it can be noticed from the graph above that the best orientation for Kathmandu is for 0 which is followed by 90. The inclinations such as 30, 60, 120 and 150 don't seem to be appropriate for Kathmandu. Hence, buildings orienting 0 and 90 are preferable.

7.3 Trend of real on-site space heating /cooling Energy Demand as per questionnaire survey



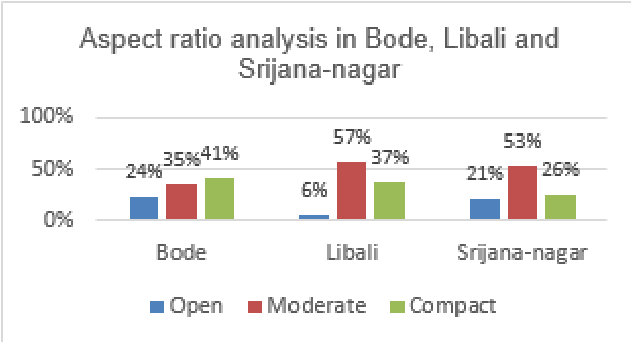
In the previous section of paper, the energy consumption for space heating/cooling the building when thermal comfort band is maintained is mentioned. However, realistic data might differ due to several reasons such as economic level, number of occupants residing inside the house, lifestyles, occupation, behaviours etc. The above chart shows that the real energy consumption of Bode is the least, followed by Libali and Srijana-nagar has the highest energy consumption for space heating/cooling.

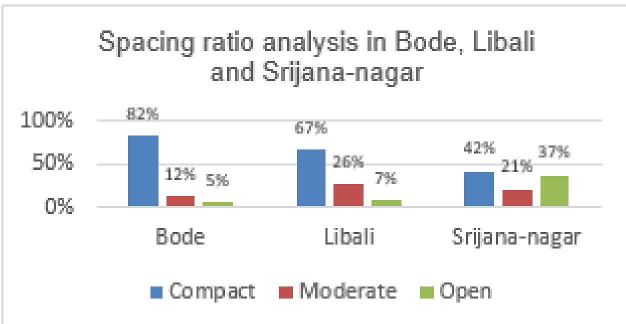
8. Discussion

8.1 Discussion on energy consumption of three sites when thermal comfort band is maintained throughout the year in all buildings

8.1.1 Heating and cooling load

Bode has the least heating load which is 95.5 kWh, followed by Libali which is 104.5 kWh and Srijana-nagar has the highest which is 105.82 kWh. Libali has the least cooling load which is 36.8 kWh, followed by Srijana-nagar which is 45.8 kWh and Bode has the highest cooling load which is 49.6 kWh.





It can be noted from the graph above that Bode is the most compact in terms of spacing ratio, followed by Libali and then Srijananagar. Heat loss can be made minimum if the spacing ratio is minimum and Bode is a compact settlement which can be the reason for its least heating load.

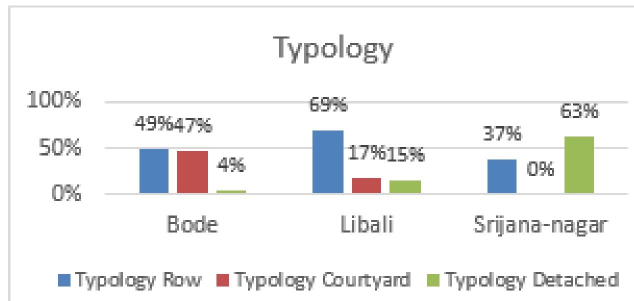
8.1.2 Total load

If the total energy consumption is to be considered, Libali counts for least energy consumption which is 141.6 kWh, followed by Bode which is 145.1 kWh and Srijananagar has the highest energy consumption which is 151.7 kWh.

	D/L2 (Width Ratio)						
	0.4	0.7	1	1.4	2	2.5	>2.5
Bode	0	8	14	25	18	8	1
Libali	4	15	16	17	2	0	0
Srijana-nagar	3	7	8	12	8	0	0

Simulation results from ECOTECT shows that having width to length equals to 1 i.e. D/L2=1, which is square shape, is the most efficient in terms of spacing heating/cooling load. Bode has 19% of buildings concurring to shape square whereas Libali has 30% of buildings adhering to D/L2=1 and Srijana-nagar has 21% of square shaped buildings.

Also, results of simulation stated that buildings having orientation 0 or 90 are the most efficient ones. Bode has almost all the buildings of either 0 or 90. However, the overall planning of Bode has been in inclination towards NE which may be due to its prevailing wind direction. Libali has 50% of buildings in 0 and 20% of buildings have 90. This might be because of the grid planning as it is a land-pooled area and thus all the sites are aligned EW or NS. Srijana-nagar has haphazardly oriented buildings in accordance with its haphazard road alignment and has 58% of buildings having 60 orientation.



Furthermore, planning also impacts energy consumption in buildings. Simulation results suggests that row house are the most efficient. However, courtyard typology was similar but lower to row houses and detached houses has the highest energy load. Bode has mostly row and courtyard houses with 49% and 47% while Libali has prominently more row typology with 69%. And Srijananagar, as is haphazard orientation, has 63% of buildings which are detached type.

Hence, for these reasons, Libali seems to be least energy consuming in terms of space heating/cooling and Srijananagar seems to be the highest consumer of energy when space heating/ cooling is concerned.

8.2 Discussion on energy consumption of three sites compared to its real on-site consumption (Data from Questionnaire Survey)

Bode consumes least energy for heating and cooling at present. That might be because it has the mixture of traditional and modern buildings and according to the simulation results, traditional house can decrease up to 86.9% of total annual load as compared to modern house due to its buildings materials which has higher insulation.

Further, average number of economically active people per house for Bode is 3.43 whereas it is 6 for Libali and 6.5 for Srijananagar which also might be one of the cause for its low energy consumption since income guides amount of energy spend in household. People tend to compromise with their comfort level and prioritize their basic need first when income is low. This might be due to the reason that 63% of people's occupation of Bode is agriculture whereas for Libali it is business with 55% and service for Srijananagar with 56%. Further, most of the houses of Libali and Srijananagar are rented with which is not for Bode.

	Annual Heating Load (Wh) per m2	Annual Cooling Load (Wh) per m2	Annual Total Load (Wh) per m2
Modern house	293677	294716	**588393**
Traditional Newari House	63227	13527	**76754**

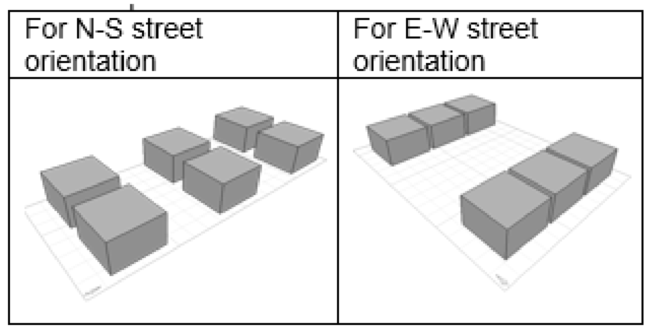
Also, the presence of courtyard planning triggers people to spend time at evening outdoor, so that heating/cooling can be skipped inside the building. Further, only 19% of houses of Bode has private landscape whereas 56% of houses of Srijananagar has private landscape and 80% of houses of Libali has private landscape. The fact that Bode is comprised of compact planning and open spaces are public spaces which contribute not only to energy efficiency but also enhances social interaction.

Thus, for these various reasons, energy consumption for space heating/cooling for Bode is lowest.

9. Conclusion

Urban form, urban geometry, urban density and orientation are the parameters which significantly affects the space heating/cooling energy spend in the buildings. Other parameters also play vital roles such as behavior, materials, lifestyles, availability and use of public spaces etc. Urban morphology is a prominent factor which can be planned beforehand during planning of new town and bring buildings to a more thermally comfortable environment so that heating/cooling load is less required and thus, having some guidelines can work as a spine line for achieving resiliency in energy consumption.

- Courtyard house typology is preferred for Kathmandu.
- 0 and 90 orientation with the longer south façade along 0 orientation.
- Square type of buildings were found to be most appropriate.
- Houses which are close to each other are found to be suitable.
- Urban geometry layouts preferred in Kathmandu valley for EW and NS street orientation is given below as it allows compactness and possibility of harnessing solar potential at the same time.



Recommendations

Due to the lack of wind data for the site, wind analysis could not be done. However, combination of thermal, wind and daylight analysis can give a clearer picture to the analysis. Thus, future work can incorporate wind analysis with thermal analysis in order to give more precise and accurate picture of the urban energy planning guidelines.

10. Acknowledgement

The author expresses a deep gratitude to the Department of Architecture and Urban Planning, Pulchowk Campus for constant encouragement and support in bringing this work to this shape.

References

[1] Nicole Miller. *Urban form and building energy: quantifying relationships using a multi-scale approach*. PhD thesis, University of British Columbia, 2013.

[2] Luc Adolphe. A simplified model of urban morphology: application to an analysis of the environmental performance of cities. *Environment and planning B: planning and design*, 28(2):183–200, 2001.

[3] Michael Doherty, Hitomi Nakanishi, Xuemei Bai, Jacqui Meyers, et al. Relationships between form, morphology,

density and energy in urban environments. *GEA Background Paper*, 28, 2009.

[4] B Rimal. Dynamics of land cover change in kathmandu, nepal. *Everest Geo-science and Information Service Center Kathmandu, Nepal*, 2012.

[5] Sushil B Bajracharya. The thermal performance of traditional residential buildings in kathmandu valley. *Journal of the Institute of Engineering*, 10(1):172–183, 2014.