Proceedings of IOE Graduate Conference, 2019-Summer
Peer Reviewed
Year: 2019 Month: May Volume: 6
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Impact of Building Envelope in Energy Demand of a Mixed-Use Residential Building: A Case Study in Kathmandu Valley

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Abstract

The rapid growth in population, an increase of 60% in every 10 years of the interval in Kathmandu only as per NHPC report in 2011 and housing demand in Kathmandu valley has led to increase in mixed-use residential development which is characteristic of residential with commercial or institutional uses. This has led to more energy use. Studies have shown that in 2010, the residential sector alone consumed 87% of total energy which is more than half of all delivered energy consumption across the country. The current practice of building construction in the valley has largely ignored the effective measures that could be applied to optimizing energy use in the mixed use residential building. In this context, it can be argued that when a building is required to achieve a high level of indoor comfort condition for its users in an efficient way, building envelopes need to be looked at to achieve such efficiency measures. This research aims at finding out the optimized building model for the mixed-use residential building. The mixed method research strategy is used in which energy consumption pattern and the building envelopes were studied using a questionnaire survey method and performance modeling of building envelope respectively. Brick as the material prevailing in the construction for envelope in the case area was chosen. Findings suggested that the annual energy demand could be reduced to 13% to 24% according to the alternative wall material chosen. And about 18% energy demand can be reduced by the use of composite building mechanism on brick walls. Whereas further results have shown that 4 to 5% of more energy can be saved by basically acting on double glazed windows. The results and conclusions of the study are applicable to new construction, energetic rehabilitation projects, and/or the improvement of existing buildings.

Keywords

Building Envelope, Energy consumption, Building envelope parameter

1. Introduction

Energy demand has become an important agenda among all countries. With the limited supply of energy, the demand to power industrialized society is increasing day by day. The future global economy is likely to consume more energy with the rise in energy demand of many developing countries. In this, the global buildings sector is responsible for 30% of energy consumption and more than 55% of electricity demand. Every year since 2010, the use of energy in buildings and CO2 gas emission has grown by nearly 1% and electricity by 2.5% [1].

In Nepal, the energy consumption by residential buildings accounts for 89% of the total energy consumption of national consumption in 2010[2]. However, the rapid growth in population, an increase of 60% in every 10 years of the interval in Kathmandu only as per NHPC report in 2011 and housing demand in Kathmandu valley has led to increase in mixed-use residential development which is characteristic of residential with commercial or institutional uses. All this increase in population, urbanization and modern lifestyle has further enhanced the energy consumption in the building sectors. Besides that, the energy consumption is increased due to the poor thermal construction of the residential buildings that do not refer to climate and does not fulfill the comfort limit of the occupants in the residence. When a building is required to achieve a high level of indoor comfort condition for its users in an efficient way, building envelopes are one of the most critical components to play with. As a proper building envelope can help to minimize the use of active mechanical mean for heating and cooling purpose and reduce energy consumption. Research has been carried out to address the potential energy saving in the building by using passive solar heating and natural ventilation for residential buildings. Limited research has been published for mixed use residential building in which energy consumption accounts greater.

2. Research Objectives

The main objective is to find out finding out the optimized building model for mixed-use residential building in terms of building material.

3. Methodology

Mixed method was used for this research in which energy consumption pattern and the building envelope were studied using a questionnaire survey method and performance modeling of building envelope respectively. In this research three types of sources of data were used namely documentation, direct observation and interview. The data were collected in three stages. In the first stage, various literature on the area of energy demand, building envelope elements, and parameters were reviewed. For this purpose, the secondary data were collected from the books, reports, articles and academic research works. Energy efficient options for residential housing and its materials were studied.

The second stage included the collection of data and information about housing unit, household type and building typology of the case study area based on secondary source (viz. CBS, 2014) [3]. A specific research area named "Gongabu Mul Sadak" inside Gongabu was chosen for the quantitative survey which was followed by field study on building envelope typologies and elements in the case study area. General impression about the entire situation was analyzed and conclusions were drawn based on observation and the interviews. And based on the typology studies, a mixed use residential building was chosen. In the third stage, in-depth assessment and interview were carried out to collect information on the building envelope material, use, occupancy and energy consumption pattern of the sample building. The weather data in Autodesk Ecotect Analysis 2011 software was generated which together with building were used to simulate with reference to building orientation, form, use, type of building materials etc. The existing building was analyzed by altering the walling material to develop alternative scenarios for energy performance evaluations.

4. Method Limitation

- The study is carried out using Ecotect Simulation software program for the building typologies studied in the field. However, various parameters required for the thermal analysis (i.e. solar admittance, thermal decrement) were used from built-in data in the library of the software. Whereas the overall thermal transmittance value has manually calculated based on reliable sources and evidence data.
- Since the research focused on the energy consumption of the sample building based on its building material properties. In this, other designing parameters were not taken into consideration.
- This research did not consider embodied energy and operating cost. Therefore results generated are based on overall heat transfer value, energy efficiency and cost effectiveness of the material.

5. Literature Review

5.1 Building envelope

The building envelope is the structural barrier between the external and indoor climate in construction, working together to provide better thermal comfort [4]. The building envelope elements are wall, openings, doors and roofs. And with precise design of it, indoor heating and cooling objectives can be improved that governs the overall energy performance of the building [4]. With all this, identifying the energy consuming building components is necessary from the perspectives of building designers and owner to reduce building energy component not only through efficient building management system but also through the proper building envelope.

5.2 Building envelope parameters

5.3 Thermal mass

It is the ability of a material to absorb and store heat energy. A lot of heat energy is required to change the temperature of high density materials like concrete, bricks and tiles [5]. They are therefore said to have high thermal mass. The thermal mass of the building envelope can contribute to the overall thermal mass of the building and be used in energy efficient buildings to store heat and 'coolness'. Thermal mass has been evolved as strategies of conservation of energy, even though it always has been an aspect of the building. Proper use of thermal mass has an important aspect in the design of climate-responsive sustainable building [6].

5.4 Thermal conductivity (k- value)

It can be defined as the rate at which heat is transferred by conduction through a unit cross-section area of a material, when a temperature gradient exist perpendicular to the area [7]. Thermal conductivity is a measurement of how much heat will move through a given amount of material. Thicker layers of material with higher thermal conductivity values will be required to achieve the same degree of insulation as materials with a lower value.

5.5 Thermal transmittance (U-value

U-value is the rate of transfer of heat through a structure (which can be a single material or a composite), divided by the difference in temperature across that structure [8]. The unit of measurement is W/m^2K. Lesser the U-Value of the material, higher is the energy performance. Thermal transmittance takes heat loss due to conduction, convection and radiation into account [8].

5.6 Relation between building envelope and energy demand

The thermal performance of the building envelope influences the energy demand of a building in two ways. It affects annual energy consumption, therefore the operating costs for building heating, cooling, and humidity control. It also influences peak loads which consequently determine the size of heating, cooling and energy generation equipment and in this way has an impact on investment costs. In addition to energy saving and investment cost reduction, a better insulated building provides other significant advantages, including higher thermal comfort because of warmer surface temperatures on the interior surfaces in winter and lower temperatures in summer [9].

6. Case Study

Gongabu is a peri- urban area which is characterized by modern RCC frame structure or load bearing wall system building created after the completion of 27 km ring road. It lies in Tokha municipality (created on 2 December 2014) in Kathmandu valley. Gongabu has got the maximum number of a housing unit in comparison to another place inside Tokha municipality as per NHPC report in 2011. Whereas about 70% of housing units are rented with mixed use housing units. However in the specific case study area i.e. Gongabu Mul Sadak, it has got a total of 85 number buildings in which 74% of buildings were mixed use residential buildings as per site survey. This area starts from Gongabu chowk and end towards the Ganesh than Temple towards the north. The total distance covered is about 0.5 km heading towards the north where the settlements are at the east and west side consisting of a total numbers of 85 buildings which include commercial and mixed use residential building. And based on the variable identified, a mixed use residential building is chosen.

Figure 1: Case building

6.1 Building Energy Model

This sample building is situated 200 meters from Gongabu chowk heading towards Manamaiju in the north. It is constructed at the west of the plot next to the road facing towards the east. The house belongs to Mr Pupan Singh and further information with the detailed interview was carried out with Rakesh Singh who is the father of the owner. The house is in the row housing unit where there are adjacent building at all three sides. It is a 4 storey RCC frame structure. Additionally, the walls are made of brick with cement mortar in which the external wall is 9 inch thick with plaster on interior and exterior whereas interior wall are 5 inch thick. It is a mixed-use residential building where lower 2 stories are rented for product display and office with beauty training center and upper storey is owned.

The dimension from plans and elevations has been verified as per actual building construction and modeling has been done. The model of the building is made by assigning different zone on each floor inside the building depending on the use, occupancy. Average annual comfort range of Kathmandu is incorporated by analyzing 10 years climatic data from 2007 to 2016. And the output shows that the average comfort range for both winter and summer lies between 20.8oC to 25.8oC. In this each zone is assigned with its own occupancy, lighting level, air change rate, wind rate and hours of operation. The hours of operation is based on the operation schedule assigned as Saturday as standard weekends and other days as working days for the commercial area.

7. Data Analysis

Autodesk Ecotect Analysis 2011 simulation tool is used for assessing the thermal comfort of the building. Ecotect uses the weather files for simulation. After combining the weather file in Ecotect, thermal analysis was the major concern to study the comfort level of the house. Monthly heating/ cooling loads were calculated for different scenarios for thermal analysis.

Table 1: Different scenarios for energy optimization according to building envelope

Scenario	Building envelope
1.	Base case
2	AAC Solid wall
3	AAC Composite wall
4	Composite Brick wall with 50mm air cavity wall

For the energy modeling of the building, the analysis is done by changing the building envelope of the base model into three different scenarios basically acting upon building material. Different scenarios for energy optimization according to the building envelope is given in Table 1.

From the building energy model, the following results have been found which is given below.

7.1 Baseline scenario

In the base case scenario, the actual building material and its composition regarding wall, flooring, door and windows were incorporated in the model with their thermal transmittance value. The adjacent building in all three sides has been considered as it plays important role in energy simulation. Thermal conductivity value of burnt brick (k-value): 0.84 W/M2 C [10].

Table 2: U-value of different building material used in the baseline scenario

Building materials	U-value
110mm thickness brick wall	2.53 W/m2 °C
230mm thickness brick wall	1.83 W/m2 °C
125mm RCC slab with HCC flooring	2.63 W/m2 °C
Tile flooring	2.69 W/m2 °C
Marble flooring	2.61 W/m2 °C

Table 3: Monthly heating and cooling loads for the baseline scenario

MONTHLY HEATING/COOLING LOADS
All Visible Thermal Zones
Comfort: Zonal Bands
Max Heating: 26.988 kW at 20:00 on 12th January
Max Cooling: 19.808 kW at 15:00 on 20th May

	HEATING	COOLING	TOTAL
MONTH	(kWh)	(kWh)	(kWh)
Jan	2935.289	0	2935.289
Feb	1235.929	0	1235.929
Mar	225.498	20.246	245.745
Apr	0	790.714	790.714
May	0	1306.113	1306.113
Jun	0	757.722	757.722
Jul	0.763	202.252	203.014
Aug	0	81.731	81.731
Sep	5.640	71.037	76.677
Oct	131.962	31.054	163.016
Nov	820.654	0	820.654
Dec	2066.612	0	2066.612
	7422.347	3260.869	10683.216
PER M²	20.726	9.106	29.832
Floor Area:	358.114 m2		

Results for the base case scenario of the sample building is shown in the Table 2, which shows the total load of 10683.216 kwh with a total cooling load of 3260.869 kwh and total heating load of 7422.347 kwh. The baseline scenario of the sample building consumes 29.832 kwh per m2 area per year.

7.2 Scenario 1- AAC blocks with solid wall

In scenario 1, Autoclaved Aerated Concrete (AAC) is used as an alternation in the wall material. It is one of the eco- friendly and certified green building materials. It is a lightweight, load-bearing, high insulating, durable building product, which is produced in a wide range of sizes and strengths [11]. Thermal conductivity value of AAC Block (k-value) is 0.16 w/m2 k [12].

Table 4: U-value of different building material used in scenario 1

Building materials	U-value
200mm thickness AAC Block	0.606 W/m2 °C
100mm thickness AAC Block	0.97 W/m2 °C

Table 5: Monthly heating and cooling loads for scenario 1

MONTHLY HEATING/COOLING LOADS
All Visible Thermal Zones
Comfort: Zonal Bands
Max Heating: 22.247 kW at 20:00 on 12th January
Max Cooling: 16.231 kW at 15:00 on 20th May

	HEATING	COOLING	TOTAL
MONTH	(kWh)	(kWh)	(kWh)
Jan	2432.029	0	2432.029
Feb	1039.072	0	1039.072
Mar	193.754	20.169	213.923
Apr	0	748.433	748.433
May	0	1164.069	1164.069
Jun	0	687.678	687.678
Jul	0.669	206.606	207.275
Aug	0	147.274	147.274
Sep	5.565	86.999	92.564
Oct	112.134	57.262	169.396
Nov	697.482	0	697.482
Dec	1723.489	0	1723.489
TOTAL	6204.194	3118.49	9322.684
PER M²	17.325	8.708	26.033
Floor Area:	358.114		

Results for alternation scenario 1 of the sample building is shown in the Table 5, which shows the total load of 9322.684 kwh with a total cooling load of 3118.49 kwh and total heating load of 6204.194 kwh. The alternation in the building of scenario 1 consumes 26kwh per m2 area per year.

7.3 Scenario 2- Composite aac block

For this composition, 100mm thick AAC block is used to make a composite wall of a 50mm air gap.

Table 6: Monthly heating and cooling loads for scenario 2

MONTHLY HEATING/COOLING LOADS
All Visible Thermal Zones
Comfort: Zonal Bands
Max Heating: 19.294 kW at 20:00 on 12th January
Max Cooling: 13.828 kW at 15:00 on 20th May

	HEATING	COOLING	TOTAL
MONTH	(kWh)	(kWh)	(kWh)
Jan	2170.219	0	2170.219
Feb	950.558	0	950.558
Mar	200.238	18.538	218.776
Apr	0	609.679	609.679
May	0	954.263	954.263
Jun	0	551.607	551.607
Jul	0.839	158.832	159.671
Aug	0	106.181	106.181
Sep	5.896	57.428	63.324
Oct	113.073	48.93	162.003
Nov	662.855	0	662.855
Dec	1554.782	0	1554.782
TOTAL	5658.46	2505.458	8163.918
PER M²	15.801	6.996	22.797
Floor Area:	358.114		

Results for alternation scenario 2 of the sample building is shown in the figure above, which shows the total load of 8163.918 kwh with total cooling load of 2505.45 kwh and total heating load of 5658.46 kwh. The alternation in the building of scenario 2 consumes 22.7 kwh per m2 area per year.

7.4 Scenario 3- composite brick wall

The composite brick wall is a masonry technique, where the bricks are used in a way which creates a cavity within the wall. The exterior face of the wall has got a double brick wall with 4” inch thick wall and interior wall is half brick wall of 4” thick making 2 inch air gap in between them.

Table 7: Monthly heating and cooling loads for scenario 3

MONTHLY HEATING/COOLING LOADS
All Visible Thermal Zones
Comfort: Zonal Bands
Max Heating: 21.165 kW at 20:00 on 12th January
Max Cooling: 15.255 kW at 15:00 on 20th May

	HEATING	COOLING	TOTAL
MONTH	(kWh)	(kWh)	(kWh)
Jan	2353.978	0	2353.978
Feb	1018.984	0	1018.984
Mar	206.173	20.072	226.245
Apr	0	657.773	657.773
May	0	1044.363	1044.363
Jun	0	588.686	588.686
Jul	0.454	167.29	167.744
Aug	0	93.63	93.63
Sep	5.674	55.508	61.182
Oct	118.375	45.624	163.999
Nov	705.944	0	705.944
Dec	1681.261	0	1681.261
TOTAL	6090.843	2672.946	8763.789
PER M²	17.008	7.464	24.472

Results for alternation scenario 4 of the sample building is shown in the figure above, which shows the total load of 8763.78 kwh with a total cooling load of 2672.94 kwh and total heating load of 6090.84 kwh. The highest amount of cooling load which is 1044.36 kwh which falls in the month of May while the highest amount of heating load which is 2353.97 kwh in the month of January.

8. Data Findings

8.1 Annual Heating load

According to a calculation made by ECOTECT Analysis, the total annual heating loads for all scenarios are given below.

Table 8: Annual Heating load

	Heating load (kwh)
Existing scenario	7422.348
Scenario 1	6204.196
Scenario 2	5658.461
Scenario 3	6090.842

The table above shows the annual heating load of all scenarios. Results for annual heating loads comparison of all scenarios for the sample building is shown in the figure above, which shows that the heating load has decreased with the alternation in the material.

Table 9: Heating Energy saved

Energy saved	Heating load
Scenario 1	16.4 %
Scenario 2	23.8 %
Scenario 3	17.9 %

The annual heating load has decreased by 16.4 % in scenario 1, 23.8% scenario 2 and 17.9% in scenario 3. The highest amount of heating load saved annually is 23.8 % in scenario 2 which is with composite AAC block.

8.2 Annual Cooling load

Table 10: Annual Cooling load

	Cooling Load (kwh)
Existing scenario	3260.867
Scenario 1	3118.489
Scenario 2	2505.458
Scenario 3	2672.945

The table above shows the annual cooling load of all scenarios.

Table 11: Cooling Energy Saved

Energy saved	Cooling Load
Scenario 1	4.4 %
Scenario 2	23.2 %
Scenario 3	18 %

The annual heating load has decreased by 4.4% in scenario 1, 23.2 % scenario 2, and 18% in scenario 3. The highest amount of cooling load saved annually is 23.2 % in scenario 2 which is with composite AAC block.

8.3 Overall annual energy saved in all scenarios

Table 12: Annual Energy saved in all scenarios

ENERGY PER YEAR (kWh)	Base case	Scenario -1	Scenario - 2	Scenario -3
Total Consumption	10683.21	9322.685	8163.92	8763.787
Energy Difference		1360.53	2519.295	1919.428
Energy Saved %		13%	24%	18%

The overall annual energy consumption is saved by 13 % by using autoclaved aerated concrete blocks of 200mm thick in the outer wall and 100mm thick AAC in an interior wall. While the highest of 24% of energy is saved by using AAC composite wall (100mm) of cavity 50 mm thick. And about 18% of energy is saved by using the composite brick wall.

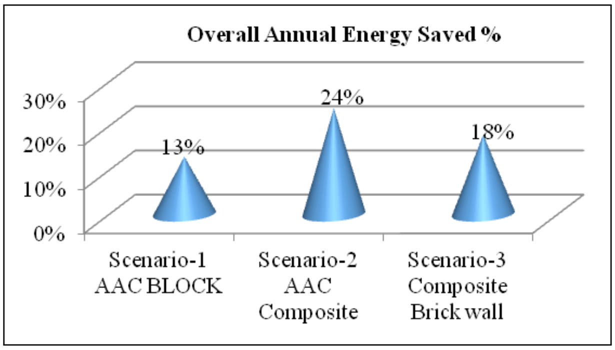

Figure 2: Overall Annual Energy saved

Table 13: Annual energy saved by the use of double glazed windows

ENERGY PER YEAR	Scenario-2	Scenario-2 + Double Glazing	Scenario-3	Scenario-3 + Double Glazing
Total Consumption (kWh)	8163.92	7780.383	8763.78	8336.628
Energy Difference (kWh)		383.537		427.159
Energy Saved %		4.6%		4.8%

The above results show that by incorporating double glazed window, about 4 to 5 % of energy can be further saved.

9. Conclusion

The following conclusions have been drawn from this research:

- The improvement in mixed use residential building can be achieved through improvement in building envelopes such as walls and glazing.
- The simulation result shows that the best optimized case is scenario 2 of composite AAC wall having an air gap of 50 mm between the internal and external wall. And about 24% of annual energy can be saved by the used of composite AAC wall.
- And 18% of energy demand can be reduced by the use of composite building mechanism on brick walls.
- Whereas further results have shown that 4 to 5% of more energy can be saved by basically acting on double glazed windows.

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