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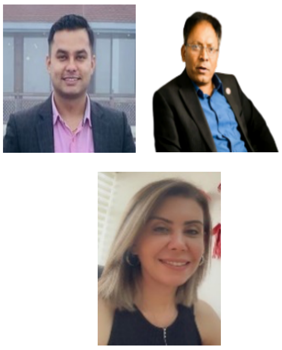
Simulation of Passive Thermal Technique and Renovation of an Existing Reinforced Concrete Residential Building: A Case Study of a Building on Tokha Municipality, Kathmandu, Nepal



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ABSTRACT

The transformation of conventional buildings towards an energy efficient buildingis soaring in the urban development of Nepal.Since, Nepal is considered as highly seismic zone, the buildings are seriously concerned to seismic resistant design mainly after Gorkha earthquake 2015 AD. Aged buildingswhich have withstood several earthquakes and have fulfilled its serviceability to the occupants undergoes renovation now days for athermal comfort.

This study focuses on the retrofitting of an existing building with passive technique for thermal comfort along with strengthening. Based on e-mail and field surveydata the simulation in ECOTECV11and ETABSV18 were carried out for energy modelling and structural analysis. The energy consumption for spaceheating and coolingon applying passive thermal retrofitting techniques were compared before and after retrofitting based on climatic data. Only four retrofitting techniques are used in this simulation; replacement of brick infill wall by EPS panel on top floor, use of insulation on ceiling and floor, reduction of infiltration and application of windows glass. Similarly, after energy retrofit, analysesof base frame, frame with infill wall and retrofit frame were studied comparatively based on fundamental time period, Base/story shear and Story displacement taking bare frame as a reference case. The susceptible structural elements – few beams and columns were retrofitted through reinforced concrete (RC) jacketing and fiber reinforced polymer (FRP) jacketing.

Results showed that infillwall and window alternation with change in orientation, size and material type enhances the thermal aspect of the building but affects the strength of the building against the future earthquake. It concluded that if any alternation in an aged building is made to enhance the thermal comfort of the building through passive technique the building must be strengthened.

Keywords: Building energy efficiency, Thermal Comfort, Passive retrofit, Simulation, Strengthening.

1. INTRODUCTION

Building construction in Nepal is evergreen sector with the adaptation of varied architectural design now days. The replacement rate of existing buildings by new construction is only 1-3% annually[1]. Since, Kathmandu valley is prone region to earthquakes, buildings are more focused to seismic resistant design mainly after the massive causalities of human life and devastation of buildings which were not structurally sound and having several deficiencies in buildings during the Gorkha earthquake 2015[2]. The governing Nepal Building Code (NBC) and guidelines NBC: 206:2015 for architectural requirements and NBC: 105:2020 for seismic considerations were then revised and regulated by Department of Urban Development and Building Construction (DUDBC), Government of Nepal (GoN) prioritizing the structural safety only whereas the concern on building's energy efficiency guidelines and regulation is still unheeded. Now-a-days, peoples choose to refurbish the buildings for thermal comfort andenergy efficiency as well as to prolong building's serviceability age. The presence of distinct seasonal and climatic variations within a small range of geographical belt urges the thermal comfort of the building as a substantial parameter in building design and construction [3] across the country. In spite of world's action on energy efficiency and building decarbonization Nepallacks the integrated guidelines, regulations and codes for building energy efficiency and structural safety.

Variouspassive retrofitting strategy were explored for thermal comfort which leads the reduction on energy consumption utilized for space heating and cooling[4].Certain researches had pointed the need of simultaneous strengthening of the structure for future earthquake on enhancing the thermal comfort by increasing the thickness of brick infill wall [5] similarly, alteration with infill walls leads the change in thermal and seismic performance of the building [6]. Any new infill materials used for energy intervention for thermal comfort in an aged buildings which is vulnerable to seismic excitation should also improve its seismic performance [7] , additionallyit hadbeen found that brick infills essentiallyassist in enhancing the strength of structure during earthquake events by resisting the lateral forces resulting less damage as compared to bare frame [8].

This paper conducts a study on an existing residential building with an energetic interventionfor thermal comfort which ultimately required the strengthening for structural strength to address future seismic events.

2. SITE SELECTION AND METHODS

The survey study was conducted in Budanilkantha and Tokha municipality which lies in northern part of the Kathmandu valley. This area was chosen to study because this region is densely populated with rampant urbanization, and was tagged as a vulnerable place for seismic event after the Gorkha earthquake2015 as shown in Fig. 1. The survey was conducted through e-mail survey and field visit interrogation based on the questionnaire prepared to assess the prevailing building conditions from an architectural and structural aspects, building thermal comfort and energy efficiency. The email survey and field visit were conducted with the obtained sample size of 110 for the population size of 57207 with the confidence level of 95% and 10% precision level based on the Yamane and Solvin's formula [9]. The responses were scrutinized and based upon it one of the existing buildings was chosen for research as a representative building which resides in Tokha municipality.

Figure 1. Extensive urban settlement following the contemporary design buildings in the Tokha municipality of Kathmandu, Nepal.

The existing reinforced concrete residential building selected for study is shown in Fig. 2. Data on building materials, architectural features, structural conditions, thermal comfort, energy consumption and inhabitant's interest for upgradation of the buidling, were recorded along with the building drawing and measurement which arerequired for simulations. The building informations are tabulated in [Table 1, Table 2].

Figure 2: Picture of East elevation (a) and South elevation (b) of an existing residential reinforced concrete building, Tokha, Nepal.

Table 1. General Architectural Description of an Existing Building.

Architectural	Description
Environment Setting	Urban
Building Design	Residential, Contemporary style, 3.5 Storey, RCC
Construction Date	2004 A.D.
Building Orientation	South-East facing
Building obstruction	In North and West by 3 storey, In South and Eastopen
Wall material	Solid Brick infill

Table 2. General Structural Description of an Existing Building.

Structural	**Description**
Column size (Ground, First, Second, Third and Top floor)	0.23m x0.23m
Beam size	0.23m x0.33m
Slab size	0.1m
Floor-to- Floor height	2.8448m
Foundation Size	1.524mx1.524m
Foundation depth	1.98m

2.2 Building Energy Modeling

Meteorology and (GoN) Government of Nepal was used in climate consultant software to predict out thermal comfort range and psychrometric chart based on which the thermal simulation was performed. The comfort range of 21 ^{0}C – 25^{0}C was accounted to maintain the indoor thermal comfort.

Initially, the model was built based upon the plan as shown in Fig 3. and the data including building orientation and building materials on floors, ceilings, doors, windows, walls, and roof along with their properties were define and internal design conditions inclusive of occupancy, internal gains, infiltration rate, parameter such as clothing, lighting level were set based upon the actual conditions of the buildingas shown in [Table 3, Table 4]. Active system in a mixed-mode, which synchronizes the effect of both natural ventilation and AC, with an efficiency of 95% was set assuming it's 24 hours operation. Occupancy schedule was considered identical for both summer and winter. Then, the model was simulated for base case scenario calculating the annual heating and cooling load whose results were compared with retrofitted model. Retrofitted model consits of an air tightness to 0.35ach, single glazed tinted window with 6mm glass, insulation on ceiling, and replacement of brick infill wall with light weight EPS panel in Top floor room as shown in Fig 4. and properties in [Table 5].

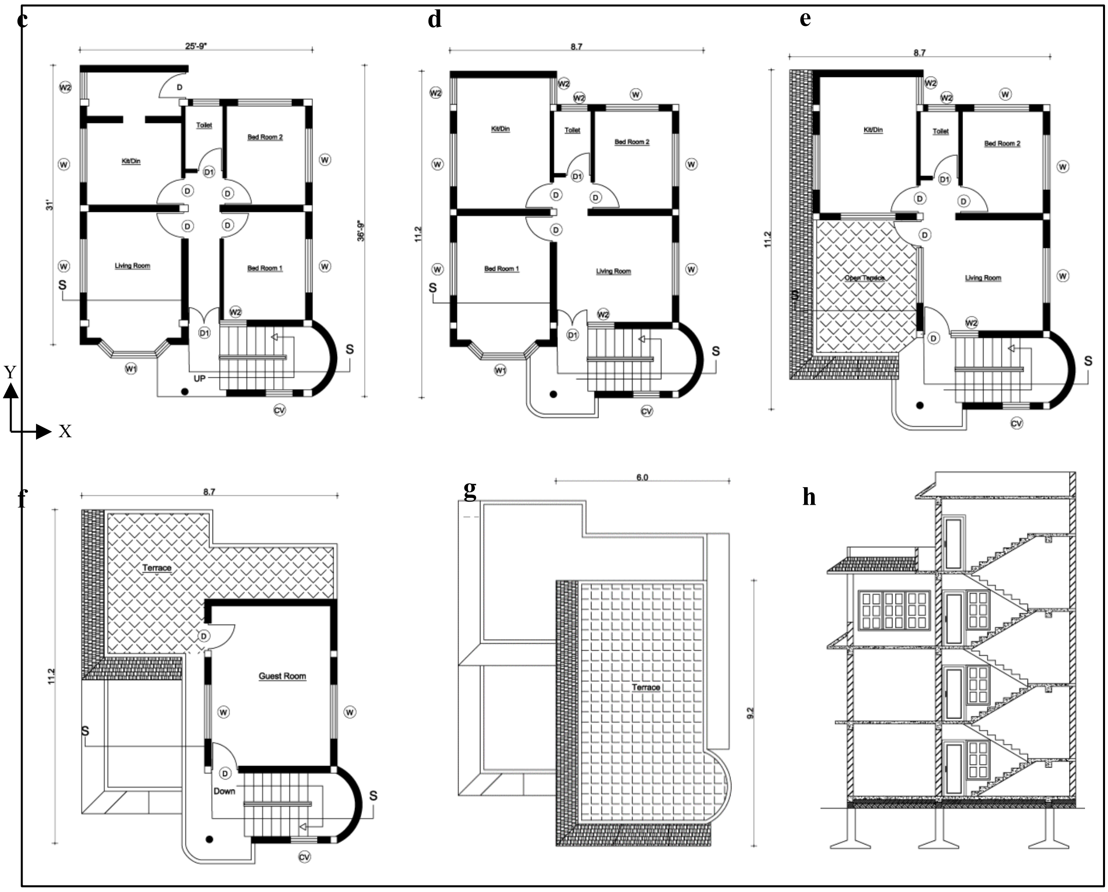

Figure 3. Existing plan view of building with solid brick as an infill wall: Ground floor (c), Second floor (d), Third floor (e), Fourth floor (f), Roof (g) and Section (h).

Table 3. Details of zone setting for base case model representing the existing building conditions.

Type of System	Mixed-Mode System
Comfort Band	21 ^{0}C – 25^{0}C
Thermal Zones	9 heated and cooled zones (Bed room & Living room) with 3 occupied passive zones (kitchen & Dinning)
Infiltration Rate	0.5 ACH
Solid Brick wall	0.23m
Window Glass	0.003m Normal glass

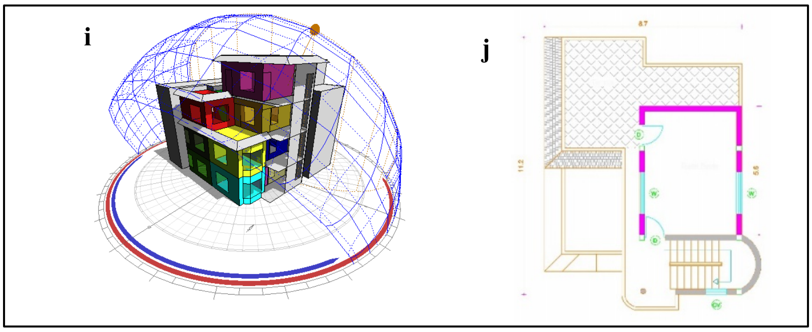

Figure 4: Ecotect model (i) for thermal comfort simulation, and brick infill wall replaced by light weight EPS panel in three sidesindicated with pink color (j).

Table 4. Materials used to define existing building in Ecotectmodel with their properties.

Materials	Components	Composition	Thickness (m)	Overall U-Value (W/m^{2}K)
Solid Brick Wall	Externall wall	plaster both side	0.230	1.39
Solid Brick Wall	Internal wall	plaster both side	0.110	1.81
Concrete	Floor slab	plaster+carpet	0.1	1.28
	Ceiling slab	plaster+Tile	0.1	2.82
	Roof	plaster	0.1	3.040
Glass	Window	Single glass pane + timber frame	0.003	5.53
Wood	Door	Solid core timber	0.032	3.690

Table 5. Retrofitting materials with their properties.

Materials	Building Components	Composition	Thickness (m)	Overall U-Value (W/m^{2}K)
Expanded polystyrene (EPS)	Infill wall Ceiling	EPS EPS	0.15 0.01	0.148 0.64
Extruded polystyrene (XPS)	Roof Slab	Concrete+XPS	0.14	0.528
Single glazed VT tinted glass	Window	Single glass pane + timber frame	0.006	3.7 (SHGC 0.4)

2.3 Building Structural Modeling

Structural analysis was performed in EtabsV18.1 to assure the strength of the building based on the data as shown in [Table 2, Table 6]. Building possesses the mass irregularities and strength related check was performed which is shown in Table 7. The load assign followed the Indian standard code IS 875:1987 part I, part I. The load combination was done for seismic forces acting horizontal direction only.The simulationwas based on the criteria for earthquake resistant design of structure [10] and seismic evaluation and retrofitting guidelines [11], [12].Building is generally designed for bare frame whereas in practical scenario the existing infill wall contributes in seismic performance of the building. The infill was model using thestrut in the frame [13], [14]. Columns and beam member in bare frame as well as after energy retrofit in infill wall frame were inadequate in strength and resulted failure in simulation as shown in Fig 5. 12 column member among 44 were strengthened with RC jacketing and 2 beam member were strengthened with FRP jacketing.

Table 6. Data of structural elements in existing building.

Material properties	**Base case**	**Retrofit case**
Concrete Grade	M15	M20
Rebar (Stirrups & longitudinal bar)	Fe250, Fe415	Fe415, Fe500
Masonry (E)	3920 MPa	3920 MPa
Section Properties		
Column	0.23mm x0.23mm	0.43mm x 0.43mm
Beam	0.23mm x 0.33mm 0.23mm x 0.23mm	
Rebar Properties		
Slab	10 mm dia.	
Beam	6-12mm dia.	
Plinth beam	6-12mm dia.	
Column	4-16 dia,4-12mm dia. & 8-12mm dia.	
Clear cover (Slab, Beam, Column) resp.	15mm, 25mm, 30mm	
Stirrups	8 mm	

Table 7. Summary of Check for Strength

Summary	**DCR(Demand Capacity Ratio)**
Column flexural capacity	check unsatisfied
Column shear capacity	check satisfied
Beam Shear capacity	check unsatisfied
Story drift	check unsatisfied

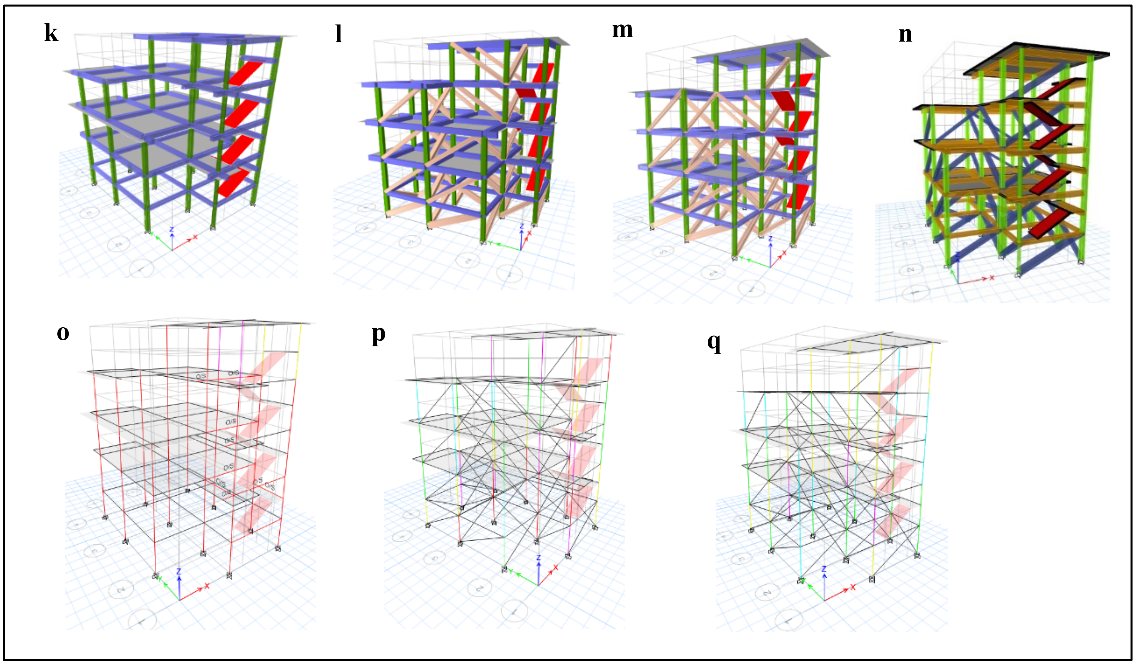

Figure 5. Structural simulation Etabs model:In bare frame (k), brick infill wall frame (l), EPS wall panel frame after energy retrofit (m),column retrofitted model (n), Failure of column and

beam member in bare frame (o), Failure of column member after energy retrofit in infill wall frame (p) and strengthen column and beam member after RC jacketing and FRP jacketing.

In this study space heating and cooling load before and after thermal simulation is compared and basic parameters base shear, story shear, story displacement and fundamental time period before and after retrofit is compared.

5. RESULTS AND DISCUSSIONS

Survey results showed that 84% of the buildings are RC framed among which 41% consist of (0.23mx0.23m) column size. 40% of the buildings were constructed in the involvement of civil engineers whereas 18% of the buildings wereowner supervised without involvement of engineers. 72% and 44% buildings were thermally discomfort in both day and night in winter and in summer respectively, which was based on the tenant's perception spending maximum time in house.Study resulted that majority of the buildings lacks the consideration of architectural aspects for energy efficiencywith passive technique as shown in Fig 6. along with structural aspects making building vulnerable to seismic excitation.76% of the building's inhabitants showed the readiness to retrofit their building for energy efficiency apart from the retrofit model and financial concerns.

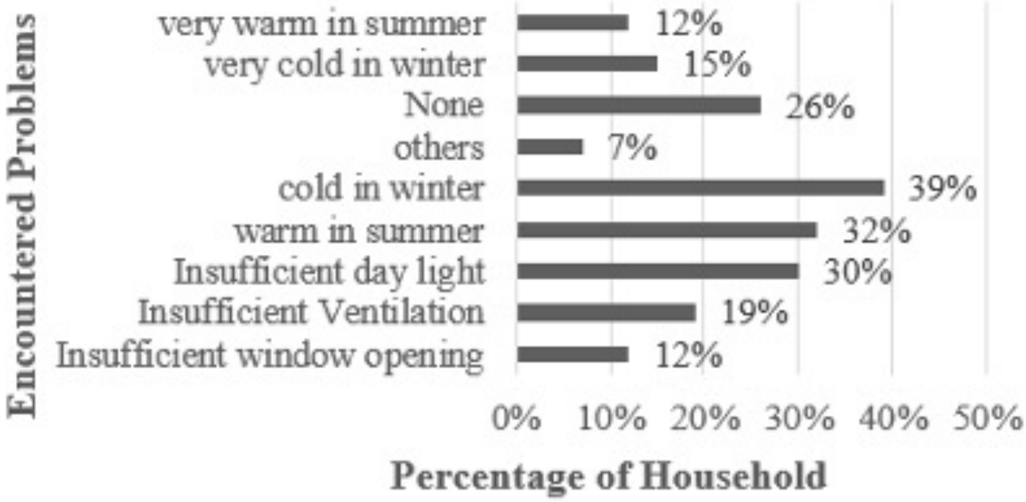

Figure 6: Architectural deficiencies encountered in buildings influencing the thermal comfort.

Ecotect simulation resulted that in top floor room, alteration with only EPS wall panel reduces the annual heating load by 11% and annual cooling load by 13%. Where with EPS panel, roof insulation, glaze window and reducing infiltration to 0.35 ach makes a significant reduction in heating and cooling energy consumption by 55%.Similarly, in second floor with ceiling insulation, glazed window and infiltration reduction cutoff the annual energy consumption for space heating by 80% and cooling by 45%. Likewise, in first floor room with ceiling insulation, glazed window and infiltration reduction, the annual heating load curtails by 82% and annual cooling load by 62% as shown in Fig 7. It signifies that passive retrofit strategy adopted in this building is much effective for reducing the heating load making building thermally comfortable in winter relatively more than the thermal comfort in summer.

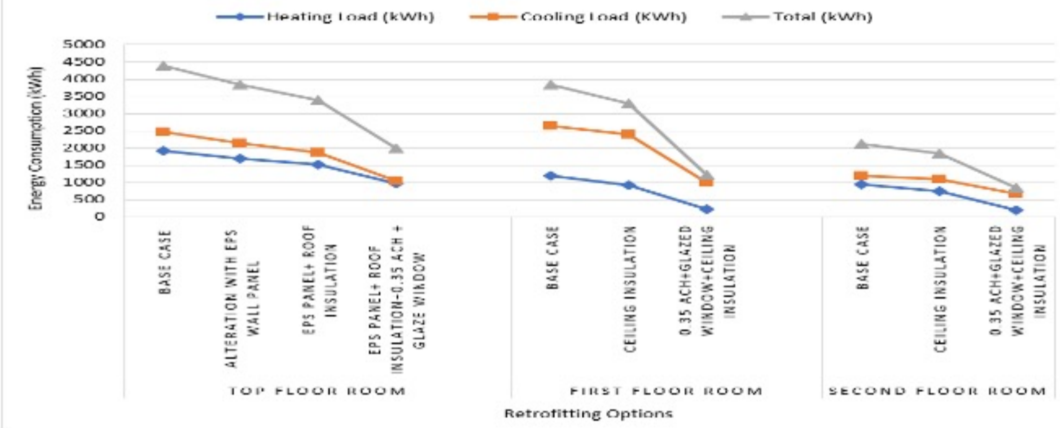

Figure 7: Comparison of annual heating and cooling load in a base case scenario with different passive techniques adopted in a building.

On strengthening the building after energy retrofit for thermal comfort, basic parameters base shear, story shear, time period and story displacement are compared as shown in Fig 8.

The time period is found highest in bare frame while least in frame after seismic retrofit. After energy retrofit with infill wall replaced by EPS panel the time period reduces to 0.48s. It showed that reducing the building weight with light weight infills makes the building mass regular and enhances the global stiffness of the building. Story shear in each floor in X-direction and Y-direction are same. The base shear is highest in bare frame and infill wall frame with value 304.189 kN. After the energy retrofit,the base shear is reduced to 294.89 kN and on strengthening the column base shear increased to 301.73 kN. It showed that decreasing heavy infill mass reduces the base shear and story shear which leads the building less susceptible to earthquakeforces attraction during earthquake excitation. In both X and Y direction, the story displacement is highest in bare frame where with infill wall it reduced tremendously. It represented that building is less stiff and is susceptible to earthquake failure in bare frame condition, where with infill walls the building stiffness increased such that building is withstanding the earthquake events without major damages. Similarly, in y-direction the story displacement in top floor with infill wall is minimum making building stiffer but after energy retrofit the stiffness decreases. It showed that infill alteration in either direction should be made stiffer to be able to withstand earthquake.

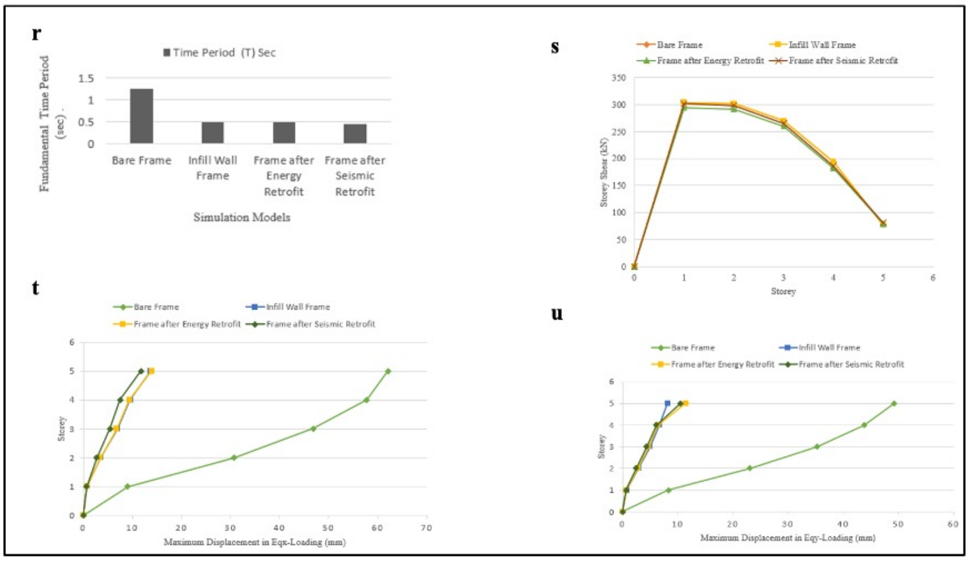

Figure 8: Comparison on fundamental time period (r), Story shear (s), Story displacement in X-direction (t), Story displacement in Y-direction(u) of all cases.

6. CONCLUSIONS

This study conducted in Budanilkantha and Tokha municipality through survey showed the inadequacy of architectural and structural features in existing building which were constructed several decades ago. Those aged buildings are still good in their serviceability function withstanding several earthquakes such as Gorkha earthquake 2015 in surging rampant urbanization but it has gone reduction in strength and several deficiencies present has made building vulnerable to future earthquake. Retrofitting for thermal comfort with passive techniques specifically with ceiling insulation, glazed windows and brick infills replaced by light weight infills enhances the overall thermal comfort of the building reducing the annual space heating and cooling load by 50% and also endorse reducing the seismic weight of building, correcting the building mass irregularities and stiffness makingless susceptible to earthquake damages. This study suggests that energy retrofit for thermal comfort with any alterations or modification incurred by infill wall mass addition or reduction in an aged building affect the building strength and performance to seismic excitation which ultimately requires strengthening to increase its strength.

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