Performance and Cost Analysis of Retrofit Strategies Applied to a Sample Single Family House Located in New Delhi India Assisted by TRNSYS Energy Simulation Tool -A Case Study

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Abstract- **This study designates an integrated passive design approach to reduce heating and cooling demand in an existing building in New Delhi, India using an improved thermal envelope and high-efficiency windows. In this study, TRNSYS 18 was used for thermal building simulation. It was found that the heating and cooling demand could be decreased significantly by improving the building thermal envelope and substituting windows with high-efficiency windows. In this study, expanded polystyrene EPS, extruded polystyrene XPS, glass wool, and still air was chosen as insulation materials for external wall and roof. Single glazed windows were replaced with high-efficiency double pane and triple pane ½" air filled windows. In the final part of the study, an investment cost analysis done for each type of retrofitting scenario is discussed.**

Keywords— TRNSYS 18, Retrofit actions, Thermal insulation, Energy simulation, Passive energy, Energy consumption and savings, Energy conservation.

I. INTRODUCTION

The increasing population growth in India is the main factor of increasing energy consumption in residential and commercial buildings. Not only in India but for the world the greatest concerns are the increasing rate of energy consumption and the accompanying greenhouse effect.

The rapidly growing use of energy in the world has already raised concerns about supply difficulties, exhaustion of energy resources, and heavy environmental impacts (global warming). The International Energy Agency has gathered frightening data on energy consumption trends. During the last two decades (1994– 2014) primary energy has grown by 49%, and CO_2 emissions by 43%, with an average annual increase of 2% and 1.8% respectively. [1]

The building sector accounts for 40% of the total final energy consumption, occupying third place after industry and transport sectors. Moreover, the expected growth of energy use in the built environment in the next 20 years is 34%, at an average rate of 1.5% per year. The residential sector will contribute to 67% of the energy consumption in 2030 and 33% will be contributed by non-domestic sector. [1]

India is an energy deficient country, where the majority of population has an inadequate provision of basic energy facilities like electricity and gas. During the fiscal year 2016-17, the gross electricity generated by utilities in India was 1,236.39 TWh and the total electricity generation (utilities and non-utilities) in the country was 1,433.4 TWh. [2,3] The gross electricity consumption was 1,122 kWh per capita in the year 2016-17.[3] India is the world's third largest producer and fourth largest consumer of electricity. [4,5] 35.5% of the population of India still live without access to electricity. [5]

Saving energy usually equals saving money and this could be a motivator for people to pursue energy solutions. The aim of this analysis/ paper is to provide a simple solution for energy savings in the buildings by retrofit strategies.

Delhi, officially the National Capital Territory of Delhi or NCT, is a city and an Union Territory of India. The NCT covers an area of 1,484 square kilometers (573 sq mi), of which 783 km^2 (302 sq mi) is designated rural, and 700 km^2 (270 sq mi) urban therefore making it the largest city in terms of area in the country. It has length of 51.9 km (32 mi) and width of 48.48 km (30 mi). According to 2011 census, Delhi's city population was about 11 million[6]. Delhi features an atypical version of the humid subtropical climate (Köppen Cwa) bordering a hot semi-arid climate (Köppen BSh). The warm season lasts from 9 April to 8 July with an average daily high temperature above 36 °C (97 °F). The cold season lasts from 11 December to 11 February with an average daily high temperature below 18 °C (64 °F). From April to October, the weather is hot. The monsoon arrives at the end of June, along with an increase in humidity [7]. According to WHO, Delhi was the most polluted city in the world in 2014. In 2016, WHO downgraded Delhi to eleventh-worst in urban air quality database [8]. During 2013–14, peak levels of fine particulate matter (PM) in Delhi increased by about 44%, primarily due to high vehicular and industrial emissions, construction work and crop burning in adjoining states [9].

Looking at the present scenario the Indian government should take measures and set targets, to stimulate building retrofits into very less (as compared to the older ones) or nearly zero energy buildings. Even though a certain percentage of the new construction is energetically more efficient, the energy retrofit of existing building is a crucial topic and attracts the interest of an increasing number of researchers.

In the present work, with reference to an existing example single-family house building, situated in central part of India, numerous different retrofit scenarios have been envisaged for the example building.

However, a thorough building retrofits evaluation is quite difficult to undertake, because a building and its environment are a complex system in which all systems influence the overall efficiency performance and the independence between the subsystems plays a significant role. In face of a large set of choices for retrofitting a building, the main issue is to identify those that prove to be the most effective in the long term. When choosing among a variety of proposed measures, the decision maker (DM) (which is often an investor) has to reconcile environmental, energy financial, legal regulation and society factors to reach the best possible compromise solution to satisfy the final occupant needs.

The numerical optimization has been performed dynamically by means of TRNSYS simulation tool [10]. TRNSYS is a widely used thermal process simulation program, which was originally developed by members of the solar energy laboratory at the University of Wisconsin for solar applications and can now be used for a wider variety of thermal processes; the first version was revealed in the year 1977. TRNSYS is an extensible simulation environment for the transient simulation of energy system including multizone buildings. It is used to validate new energy concepts, design and simulation of buildings and their equipment including control strategies, occupant behavior and alternative energy systems (Wind, Solar, Photovoltaic, Hydrogen Systems etc.).

The model created here is aimed at determination of the thermal demand with reference to a building in India, which is supposed to be located in New Delhi climate Zone. The economic analysis, with the study of simple payback period applied to climatic zone and to each retrofitting scenario, concludes the paper.

II. DESCRIPTION OF EXAMPLE CASE STUDY

The example structure is a one-floor single-family house, which was constructed in the year 1980, in central India. The dimension of the floor is 12x9 square meters. The height of the floor is 3 meters. The whole building is defined as zone1. The ventilation air is supplied to the whole building. The example building is equipped with parking and gardening space outside. Parking and gardening area is not included in this study. This building is characterized by 2 bedrooms and living room, Dining area, kitchen and one bathroom. In this house, a couple lives with two kids. The glazing area represents 17% of floor area.

A. *Construction of the building*

The construction has concrete and brick structure. The floor and the roof have concrete structure, marble is used as a surface of the floor to provide good finish, look and strength to the floor. The walls are built of cement, sand, and brick with no thermal insulation. The building has standard single glazing window, and window frames are made of wood. The doors are also made of wood. The house is south facing. The building is cooled with a conventional air conditioning systems. The important technical data with transmittance values of the studied example building is reported in Table-1.

Table-1: Technical data of studied example single family house

Building Volume (m^3)	324
Floor Area (m^2)	108
U-value external walls, $Wm^{-2}K^{-1}$	2.15
U-value floor, $Wm^{-2}K^{-1}$	1.34
U-value roof, $Wm^{-2}K^{-1}$	1.12
U-value glazing, $Wm^{-2}K^{-1}$	5.75

B. *Occupancy*

The number of occupants is four for this house (a couple with their two kids) that are present at weekdays from 17.00 to 8.00 (15 hours) and 24 hours at weekends. In order to simulate the heat gain from the people, the activity level of the occupants is set for the zone as “seated, light work”, the associated heat gains being 75 W each for sensible and latent loads. The clothing factor for the people is specified as 0.5 cloth (summer light clothing) and the metabolic rate as 2 met (house work). Another factor in the thermal comfort level is the relative velocity of air which is kept at 0.1 m/s for this study.

C. *Infiltration of building*

The infiltration for the zone is selected to be 0.5 ACH based on the histograms given in ASHRAE fundamentals (2005). [14] The fresh air ventilation rates for acceptable indoor air quality in buildings are taken from ASHRAE standard 62. 2004) [16]. As the infiltration already covers this, no additional ventilation is used

III. BUILDING SIMULATION

Nowadays various commercial programs are available for thermal simulation of buildings, e.g., EnergyPlus [21], TRNSYS [10], IDA/ICE [19], TAS [20], HAP [22] and many others. TRNSYS18, which is a coupled transient building and HVAC plant simulation tools, was used for this study.

The weather data files used in the simulation are in .tm2 format and this was downloaded directly from the TRNSYS website. The weather data is given for the each hour throughout the year. Weather data includes direct normal solar radiation, global solar radiation, global solar radiation on horizontal, dry bulb temperature, humidity ratio, wind velocity and wind direction. The Cooling Degree Days (CDD) and Heating Degree Days (HDD) values for the New Delhi are 2928 and 429 respectively [15].

For the simulation in TRNSYS, the indoor temperature set point for cooling is 24˚C and for heating 22˚C. There is no specific control for indoor relative humidity in any of the systems.

IV. RESULTS AND DISCUSSION

First, the building envelope is considered in its present state before the following discussed retrofit actions. For the actual present condition, the amount of energy required (in kWh/Year) for heating and cooling of the building in winter and summer time is 1835.2 kWh/year and 22968.30 kWh/year respectively.

A. Improved thermal envelope and high-efficiency windows

Heat balance of a building in India reveals that at least 20 to 30 % of the heat input into a building is through walls and roof. Hence, insulating walls and roof are extremely critical in the energy performance of a building [13]. The most common retrofit action which has been contemplated here initially consists of including an improved building thermal envelope and use of high-efficiency windows.

For improved thermal envelopes, a range of insulation materials can be installed in the building. In this study, the application of insulation material is done to improve the thermal envelope of the building through insulating the external wall and the deck (roof). A number of insulation materials were used like extruded polystyrene (XPS) with U-Value 0.28 and thickness 60 mm, glass wool stuffing with U-value 0.25 and thickness 150 mm, expanded polystyrene (EPS) with U-value 0.30 and thickness 100 mm, air (still) (only for external walls with U-value 0.20 and thickness 30 mm.

In the high-efficiency windows, the single glazing windows were substituted with a number of high efficiency 2 and 3 pan glazing windows filled with air with various thickness. The total thermal transmittance (frame and glazing) varies with the number of glazings and thickness of filled air between the glazings. The type of window used in the actual building is single pane glazing with the corresponding U-value 5.75 $Wm^{-2}K^{-1}$.

Using these above-mentioned insulation materials 12 different types of combinations of the assembly of external wall and roof were created. In this study 2-pane and 3-pane air filled windows were considered. The thickness of filled air is ½" each and thermal transmittance (U-value in $Wm^{-2}K^{-1}$) of these windows are 2.82 and 1.69 respectively. All studied combinations are mentioned in Table 2. Figure 1 displays the U-value of building surfaces i.e., external wall, roof, and windows of 12 different types of combinations of retrofit assembly.

Table 2. different combinations of retrofit assembly

S.No.	Possible Combinations of Retrofits	Thermal Trans-mittance, U, Wm-2K-1	Heating Energy Demand, Q, kWh/ Year	Cooling Energy Demand, Q, kWh/ Year	Total Energy Savings, Q, kWh/ Year	Estimated Cost of Retrofit in INR (Indian Rupee)	Total Cost of Retrofit (Including labor cost @25000 INR)	Estimated cost saving /year in INR (Indian Rupee)@ 7.3/unit
0	External Wall with/o Insulation Roof with/o Insulation Window Single Glazing	2.153 1.113 5.72	1835.2	22968.30	-	-	-	-
1	External wall with Extruded Polystyrene Roof with Extruded Polystyrene Window Double Pane 1/2" air space	0.45 0.377 2.82	373.73	16527.90	7901.37	55000.0 48600.0 33880.0	162480.0	57680.001
2	external wall with Glass wool stuffing Roof with Glass Wool stuffing Window Double Pane 1/2" air space	0.211 0.193 2.82	223.31	15814.90	8764.79	75000.0 66000.0 33880.0	199880.0	63982.967
3	External Wall with Expanded Polystyrene (EPS) Roof with Expanded Polystyrene (EPS) Window Double Pane 1/2" air space	0.263 0.236 2.82	254.57	15970.90	8577.53	35000.0 30800.0 33880.0	124680.0	62615.969
4	External Wall with unmoving air Roof with Extruded Polystyrene Window Double Pane 1/2" air space	0.182 0.377 2.82	287.99	16228.80	8286.21	73100.0 48600.0 33880.0	180580.0	60489.333
5	External Wall with unmoving air Roof with Expanded Polystyrene (EPS) Window Double Pane 1/2" air space	0.182 0.236 2.82	231.68	15881.98	8689.34	73100.0 30800.0 33880.0	162780.0	63432.182
6	External Wall with unmoving air Roof with Glass wool stuffing Window Double Pane 1/2" air space	0.182 0.193 2.82	215.38	15780.96	8806.66	73100.0 66000.0 33880.0	197980.0	64288.618
7	External wall with Extruded Polystyrene Roof with Extruded Polystyrene Window Triple Pane 1/2" air space	0.45 0.377 1.69	211.17	16146.08	8445.75	55000.0 48600.0 60215.0	188815.0	61653.975
8	External wall with Glass wool stuffing Roof with Glass Wool Stuffing Window Triple Pane 1/2" air space	0.211 0.193 1.69	96.33	15452.89	9253.78	75000.0 66000.0 60215.0	226215.0	67552.594
9	External Wall with Expanded Polystyrene (EPS) Roof with Expanded Polystyrene (EPS) Window Triple Pane 1/2" air space	0.263 0.242 1.69	118.42	15602.96	9081.62	35000.0 30800.0 60215.0	151015.0	66295.826
10	external wall with unmoving air Roof with Extruded Polystyrene Window Triple Pane 1/2" air space	0.178 0.393 1.69	143.02	15856.00	8803.98	73100.0 48600.0 60215.0	206915.0	64269.054
11	External Wall with unmoving air Roof with Expanded Polystyrene (EPS) Window Triple Pane 1/2" air space	0.182 0.263 1.69	102.14	15517.95	9182.91	73100.0 30800.0 60215.0	189115.0	67035.243
12	External Wall with unmoving air Roof with Glass wool stuffing Window Triple Pane 1/2" air space	0.178 0.197 1.69	91.116	15419.97	9291.91	73100.0 66000.0 60215.0	224315.0	67830.9722

Note: Cost of retrofits are calculated using some online cost calculator websites and online Indian market portal [17] [18].

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Considering the global cooling and heating system efficiency was taken constant with 0.85, In Indian market energy ratings for AC varies 1 to 5 star rating for window and split type AC. For this study we consider AC with 5 Star ratings (COP 3.5). The simulation results in terms of primary energy need for the heating and cooling purpose throughout the year is shown in Table 2 for the listed possible combinations of retrofits.

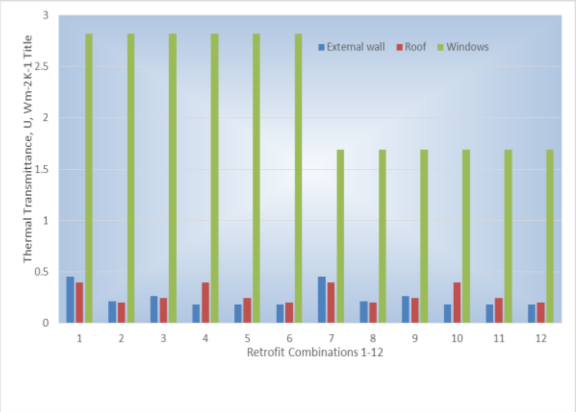


Figure 1: U-value of building materials of combinations of retrofit assembly (see table 2).

This analysis shows the amount of energy savings per year depends on the insulation material, which is used for thermal insulation of roof and external walls, and the window types. Figure 2 shows the heating, cooling energy demand and amount of energy savings for retrofit combinations 1 to 12. This analysis shows the total energy demand in buildings (for heating and cooling) can be reduced by up to 30-40% by using improved thermal envelope and high-efficiency windows together. It is also found that the cost of energy saving for the retrofit scenarios mentioned in Table 2 varies from 0.3 to 0.5 times of the cost of the retrofits in the 1st year while in the 5th year these values change to 1.5 to 2.5 (Figure 3).

This analysis also shows the maximum achievable energy saving is possible with the retrofit strategy 12 (9292 kWh/year), The annual cost saving is 30 % of the investment cost of the retrofit, while the most profitable is retrofit strategy 3 as for this retrofit scenario the annual cost saving is 50 % of the investment cost of the retrofits, The U value of the wall, roof and windows are 0.18, 0.19, 1.69 and 0.18, 0.37, 2.82 respectively for scenario 12 and 3.

Extrude polystere is used as an insulation material in strategy 3 for external wall and roof to improve thermal envelope while in strategy 12 unmoving air and glass wool is used as insulation material for external wall and roof respectively. Extruded polystere is easily available in Indian market at low cost. In this analysis we found the cost of retrofit 3 is cheaper than strategy 12 which makes the strategy 3 more promising and favorable for the users.

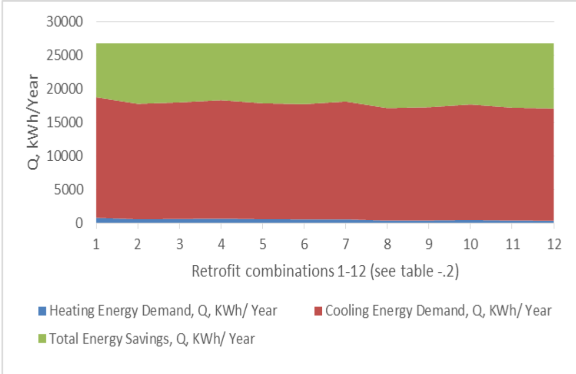


Figure 2: Heating, Cooling Energy Demand, and Amount of Energy Savings for Retrofit Combinations 1-12 (See table 2).

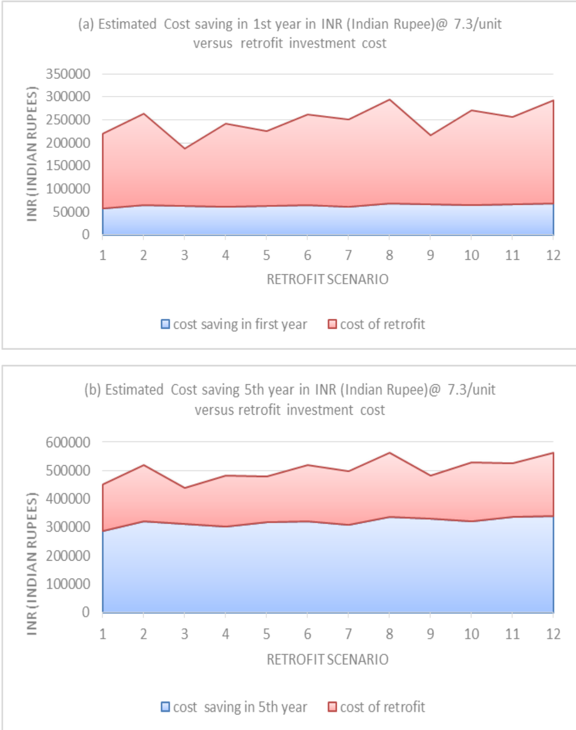


Figure 3: comparision of cost savings vs retrofit investment cost (a) in 1st year (b) in 5th year

B. *Improved thermal envelope*

In the next step, only the improved thermal envelope was considered to make a comparative analysis. At this stage, the simulation was performed only for the improved thermal envelope, insulated external wall, and roof (over the deck). The insulation material used was extruded polystyrene (XPS) with a U-Value 0.28 and a thickness 60 mm. The type of window used in this scenario is single pane glazing with the corresponding U-value 5.75 $Wm^{-2}K^{-1}$. The analysis was further split into the two following categories.

a. Assessment between roof and external wall insulation: the effect of insulation of wall and insulation of roof separately. Three combinations, of the insulated external wall (only), insulated roof (over deck only) and insulated external wall and roof both were made (See Table 3).

In this analysis, it was found that the amount of energy savings per year depends on the insulation material, which is used to improve thermal envelope through the thermal insulation of roof and external walls. This analysis shows the total energy demand in buildings (for heating and cooling) can be reduced by up to 7-16% by using an improved thermal envelope (retrofit scenarios 1,2,3, refer Table 3). It is also found that the cost of energy saving for the retrofit scenarios mentioned in Table 3 varies from 18% to 23% of the cost of the retrofits in 1st year (Figure 4). The U value for the improved thermal envelope was reduced for the external wall and roof by insulation. In this study we assumed Extruded Polystyrene as insulation material. U value of external wall and roof was 2.15, 1.11 and 0.45, 0.38 respectively for without and with insulation.

Table 3. Improved thermal envelope

S.No.	Possible Combinations of Retrofits	Thermal Trans-mittance, U, Wm-2K-1	Heating Energy Demand, Q, kWh/ Year	Cooling Energy Demand, Q, kWh/ Year	Total Energy Savings, Q, kWh/ Year	Estimated Cost of Retrofit in INR (Indian Rupee)	Total Cost of Retrofit (Including labor cost @25000 INR)	Estimated Cost saving /year in INR (Indian Rupee)@ 7.3/unit
0	External Wall with/o Insulation	2.153				-		
	Roof with/o Insulation	1.113	1835.2	22968.30	-	-	-	-
	Window Single Glazing	5.72				-		
1	External Wall with/o Insulation	2.153				0.0		
	Roof with Extruded Polystyrene (60 mm)	0.377	1489.36	21507.90	1806.24	48600.0	73600.0	13185.55
	Window Single Glazing	5.72				0.0		
2	External wall with Extruded Polystyrene (60 mm)	0.45				55000.0		
	Roof with/o Insulation	1.113	1176.3	21540.90	2086.30	0.0	80000.0	15229.99
	Window Single Glazing	5.72				0.0		
3	External wall with Extruded Polystyrene (60mm)	0.45				55000.0		
	Roof with Extruded Polystyrene (60mm)	0.377	815.05	19980.86	4007.59	48600.0	128600.0	29255.41
	Window Single Glazing	5.72				0.0		

Note: Cost of retrofits are calculated using some online cost calculator websites and online Indian market portal [17] [18].

b. Effect of thickness of insulation layer: The insulation materials are available in different thicknesses in the market. The thickness of insulation material is one of the major criteria for the section of insulation material. The effect of thickness of insulation layer on all the factors like amount of energy saving (Q, kWh/Year), cost savings (in INR), investment cost (in INR) etc. was taken into account (see Table 4).

For this analysis Extruded Polystyrene was taken as insulation material with different thicknesses (from 30 mm to 120 mm) for the insulation of external wall and roof. It was found that the amount of energy savings per year increases with the thickness of the insulation material. This is found the amount of energy savings in buildings (for heating and cooling) varies 13-19% for insulation thickness varies from 30-120 mm (refer Table 4). It is also found that the cost of energy saving for the retrofit scenarios mentioned in Table 4 varies from 0.16 to 0.3 times of the cost of the retrofits in (Figure 5). The interesting finding of this analysis is the ratio of cost of energy saving to the cost of the retrofit is highest for the retrofit scenario where the thickness of insulation is minimum i.e., 30mm. Also in this analysis, it was found that to reduce the energy demand from 13% to 19% the cost of retrofits increases by approximately 50%.

Table 4. Effect of thickness of insulation layer

S.No.	Possible Combinations of Retrofits	Thickness of insulation layer in mm	Thermal Trans-mittance, U, Wm-2K-1	Heating Energy Demand, Q, kWh/ Year	Cooling Energy Demand, Q, kWh/ Year	Total Energy Savings, Q, kWh/ Year	Estimated Cost of Retrofit in INR (Indian Rupee)	Total Cost of Retrofit (Including labor cost @25000 INR)	Estimated Cost saving /year in INR (Indian Rupee)@ 7.3/unit
0	External Wall with/o Insulation	-	2.15						
	Roof with/o Insulation	-	1.11	1835.20	22968.3	-	-	-	-
	Window Single Glazing	-	5.72						
1	External wall with Extruded Polystyrene	30	0.75				27280.00		
	Roof with Extruded Polystyrene	30	0.56	1018.30	20628.0	3157.20	23760.00	76040.00	23047.56
	Window Single Glazing	-	5.72				0.00		
2	External wall with Extruded Polystyrene	40	0.61				40920.00		
	Roof with Extruded Polystyrene	40	0.48	928.45	20345.9	3529.09	35640.00	101560.0	25762.36
	Window Single Glazing	-	5.72				0.00		

3	External wall with Extruded Polystyrene	50	0.52				48360.00		
	Roof with Extruded Polystyrene	50	0.42	863.70	20138.7	3801.07	42120.00	115480.0	27747.81
	Window Single Glazing	-	5.72				0.00		
4	External wall with Extruded Polystyrene	60	0.45				55000.00		
	Roof with Extruded Polystyrene	60	0.38	815.05	19980.6	4007.83	48400.00	128400.0	29257.16
	Window Single Glazing	-	5.72				0.00		
5	External wall with Extruded Polystyrene	80	0.36				74400.00		
	Roof with Extruded Polystyrene	80	0.31	747.05	19755.3	4301.13	64800.00	164200.0	31398.25
	Window Single Glazing	-	5.72				0.00		
6	External wall with Extruded Polystyrene	100	0.30				89280.00		
	Roof with Extruded Polystyrene	100	0.26	701.77	19601.4	4500.26	77760.00	192040.0	32851.90
	Window Single Glazing	-	5.72				0.00		
7	External wall with Extruded Polystyrene	120	0.25				100440.00		
	Roof with Extruded Polystyrene	120	0.23	669.42	19491.0	4643.08	87480.00	212920.0	33894.48
	Window Single Glazing	-	5.72				0.00		

Note: Cost of retrofits are calculated using some online cost calculator websites and online Indian market portal [17] [18].

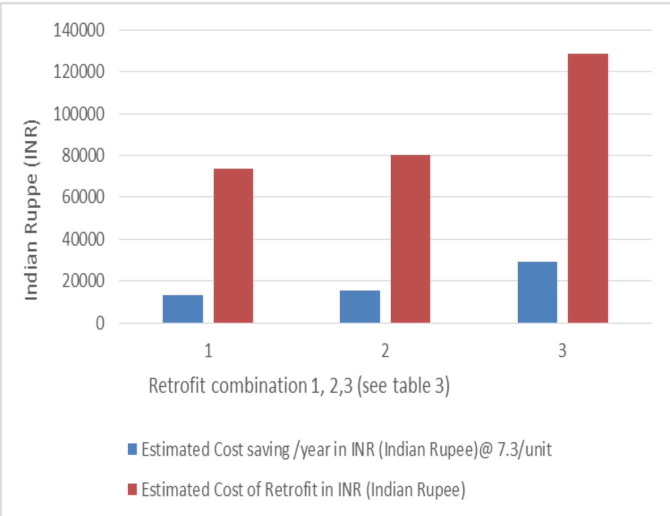


Figure 4: Improved Thermal Envelope for retrofit scenarios 1,2,3 (Table 3)

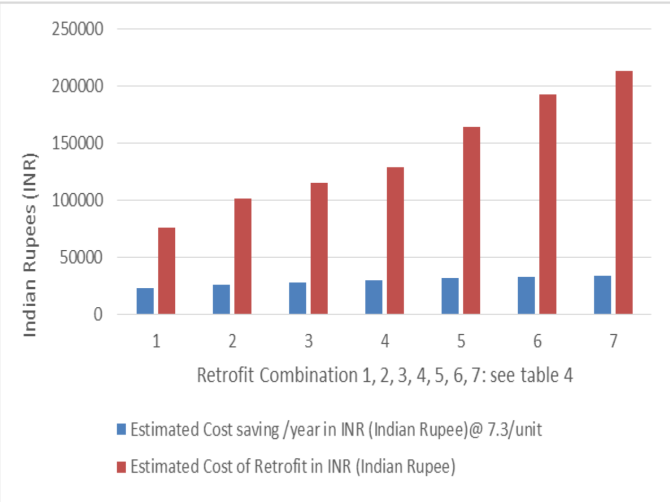


Figure 5: Effect of thickness of insulation layer for retrofit scenarios 1-7 (Table 4)c. High-efficiency windows

In this part, the simulation used high-efficiency windows in which the single glazing windows were substituted with the high-efficiency double-pane and triple-pane glazing windows filled with air with various thickness. The total thermal transmittance (frame and glazing) varies with the number of glazing and thickness of filled air between the glazings. The type of window used in the original building is single pane glazing with the corresponding U-value 5.75 Wm-2K-1. In this section the thermal envelope is considered to be in the original condition and thermal building simulation is done to find out the effect of high-efficiency windows on the factors like amount of energy saving (Q, kWh/Year), cost savings (in INR), investment cost (in INR) etc. (Table 5).

This analysis shows the total energy demand in buildings (for heating and cooling) can be reduced by up to 13-28% by using high-efficiency windows (retrofit scenarios 1,2,3 and 4, refer Table 5). It is found that the cost saving for the retrofit scenarios mentioned in table 5 varies from 40 to 70 % of the investment cost of the retrofits in 1st year (Figure 6). This studies shows the retrofit combination 3 is the most profitable retrofit for the high efficiency windows. This retrofit can reduce approximately 28% of energy demand for heating and cooling purpose and the cost saving by this retrofit is 70% of the investment cost of retrofits, which is the highest of this section. U-value of the window for 3rd retrofit scenario (Table 5) is 2.21.

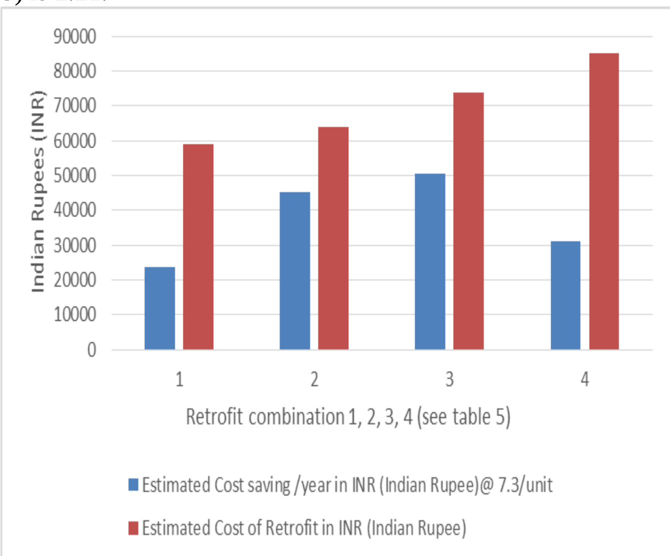


Figure 6: Effect of High-Efficiency Windows retrofit scenarios 1, 2, 3 and 4 (Table 5)

Table 5. Effect of High-Efficiency Windows

.No.	Possible Combinations of Retrofits	Thermal Trans-mittance, U, Wm-2K-1	Heating Energy Demand, Q, kWh/ Year	Cooling Energy Demand, Q, kWh/ Year	Total Energy Savings, Q, kWh/ Year	Estimated Cost of Retrofit in INR (Indian Rupee)	Total Cost of Retrofit (Including labor cost @25000 INR)	Estimated Cost saving /year in INR (Indian Rupee)@ 7.3/unit
0	External Wall with/o Insulation Roof with/o Insulation Window Single Glazing	2.153 1.113 5.72	1835.20	22968.3	-	- - -	-	-
1	External Wall with/o Insulation Roof with/o Insulation Window Double Glazing Air filled 1/2"	- - 2.82	1391.20	20183.8	3228.5	- - 33880.0	58880.0	23567.76
2	External Wall with/o Insulation Roof with/o Insulation Window Double Glazing Air filled 3/4"	- - 2.385	2121.50	16463.6	6218.4	- - 38800.0	63800.0	45394.47
3	External Wall with/o Insulation Roof with/o Insulation Window Triple Glazing 1/4"	- - 2.21	2363.50	15521	6919.0	- - 48700.0	73700.0	50508.7
4	External Wall with/o Insulation Roof with/o Insulation Window Triple Glazing 1/2"	- - 1.69	1178.50	19365.9	4259.1	- - 60215.0	85215.0	31091.5

Note: Cost of retrofits are calculated using some online cost calculator websites and online Indian market portal [17] [18].

V. INVESTMENT COST ANALYSIS

The standard tool to evaluate and compare investment propositions is the Net Present Value (NPV) method [11].
The net present value {sometimes known as net present worth (NPW)}, is a measurement of profit calculated by subtracting the present values (PV) of cash outflows (including initial cost) from the present values of cash inflows over a period of time [12]. Because of its simplicity, NPV is a useful tool to determine whether a project or investment will result in a net profit or a loss. A positive NPV results in profit, while a negative NPV results in a loss [12]. NPV is a central tool in discounted cash flow (DCF) analysis and is a standard method for using the time value of money to appraise long-term projects. It is widely used throughout economics, finance, and accounting.

Formula: The discounted value of the net cash flow is occurring in the project's lifetime from year 0, year of the initial investment I_0, to the horizon year H, and can be expressed as follows:

$$NPV\ (i,N) = \frac{\sum_{t=0}^{N} EBt}{(1+i)^t} - I_0$$

Where, $EB_t = EB_0\ (1+er)^t$

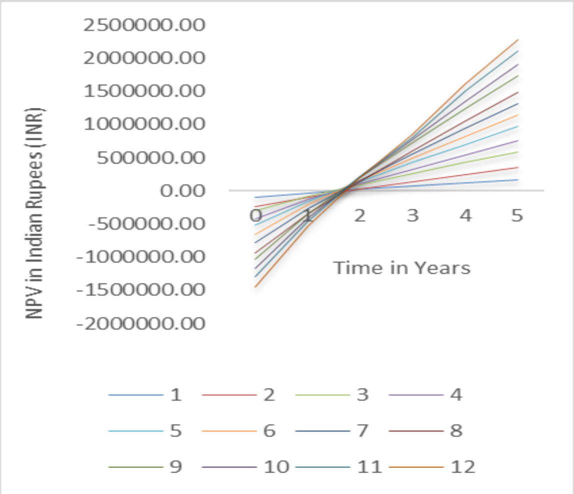
N= project horizon in number of years (index t);
i = yearly discount rate;
EB_t= energy benefits of the project in year j expressed in monetary units;
EB_0= energy benefits of the project in year 0 expressed in monetary units;
I_0 = costs of the project at the year 0;
er= yearly increment of the cost of energy.
Equation (1) determines the value of NPV, which depends on the actual cash flows in the various number of years, and on the parameters I (yearly discount rate) and I_0 (initial cost of the project). In other words, NPV is an indicator of how much value an investment or project adds to the firm/owner.

The important criteria for accepting the projects are based on NPV calculations are mentioned in following lines:

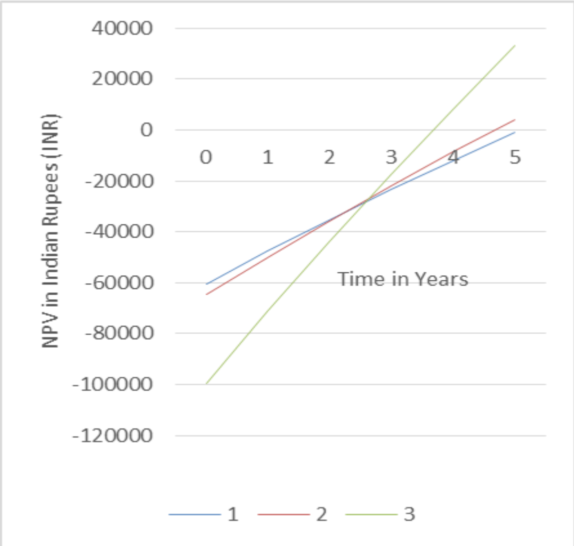
- NPV ≥ 0: the investment would add value to the firm which means the invested capital is eligible to generate a return of yearly discount rate (i) per year over the period N.
- The number of years required to bring the value of NPV from negative to positive value. The year when NPV value crosses the zero value is summarized as DPB (Discounted Pay Back). Mathematically it is expressed as,

$$NPV\ (i,\ DPB) = 0$$

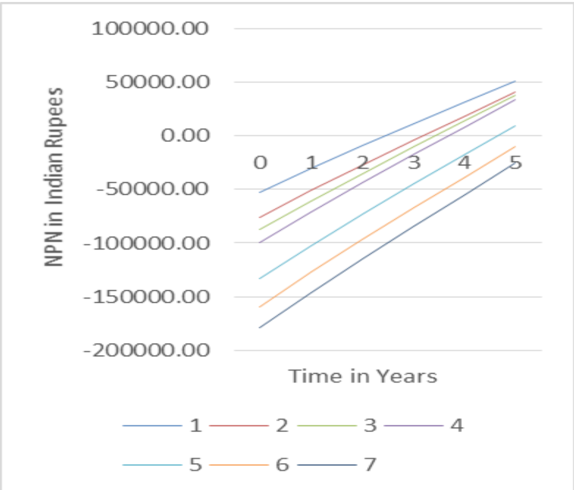
With the reference to the mentioned retrofit cases in this paper, the input data have been chosen as follows:
Yearly discount rate, i = 6%
Project horizon (number of years) = 25
Yearly increment of the cost of energy = 8.32 %
Initial investment, (I_0) and Evaluated energy savings at initial time (t=0) (EB_0) for all studied combination assembly are given in Table 2, 3, 4 and 5.
Cash flow for all studied retrofit scenarios/ combinations are shown in graph 1-4, when the building is supposed to be situated in New Delhi, India.



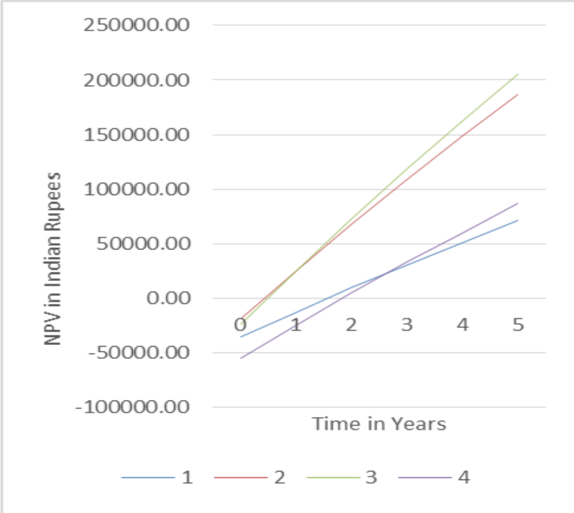
Graph 1: Cash flow for Retrofit Combinations 1-12 (see Table 2)



Graph 2: Cash flow for Retrofit Combinations 1, 2 and 3 (see Table 3)



Graph 3: Cash flow for Retrofit Combinations 1-7 (see Table 4)



Graph 4: Cash flow for Retrofit Combinations 1-4 (see Table 5)

VI. CONCLUSION

In this paper, the energy demand with reference to a building made in the year 1980 in the central part of the India, which is supposed to be located in New Delhi climatic zone was determined. Two retrofitting scenarios have been performed for the purpose of numerical investigation: Improved thermal envelope and high-efficiency windows. For these two retrofit scenarios, 12 types of retrofit combinations using 4 different types of wall and roof insulation material and 2-Pane and 3-Pane air filled windows were developed. NPV (net present value) method and Discounted Pay Back (DPB) calculation were used to perform investment cost analysis. This analysis was applied to each retrofitting combination. It can be clearly seen, that the shortest discounted pay back is achieved with the 2 pane windows. The pure insulation has a payback time up to 5 years. The retrofit combinations of table 1 nearly all pay back in about 3 years. The major findings from this work are summarized below:

-The amount of energy savings per year depends on the insulation material, which is used for thermal insulation of roof and external walls, and the window types.

-The amount of energy demand and saving also changes with the thickness of insulation material.

-The maximum amount of energy savings per year can be achieved approximately 68000.00 INR for retrofit combination “12” (Table 2) when the retrofit action is applied for improved thermal envelope as well as high-efficiency windows. This retrofit can reduce approximately 37.5% of energy demand for heating and cooling purpose and the cost saving by this retrofit is 30% of the investment cost of retrofits. But it is not the best case as retrofit combination “9” (Table 2) can reduce 36.5% of heating and cooling energy demand while the cost saving by this retrofit is 44% (approximately) of the investment cost of retrofits (Table2). The U value of the wall, roof and windows are 0.18, 0.20, 1.69 and 0.26, 0.24, 1.69 respectively for scenario 12 and 9.

-The payback time for the building located in New Delhi is **0-3 years** depending on the type of retrofit combination.

-Minimum 3300 kWh/year (approx.) and the maximum 6700 kWh/Year (approx.) amount of energy can be saved by substituting single glazing windows to double pane/triple pane glazing windows (see Table 5)

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- Retrofit scenario "3" under the high-efficiency windows (Table 5) is the best retrofit solution as the annual cost saving is 70% of the investment cost of the retrofits in 1st year which is the highest value among the all studied retrofit scenarios.

In general retrofti of buildings in Delhi/India seems to be highly cost efficient and should therfore be promoted.

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