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# TOOL FOR ENERGY EFFICIENT BUILDING ENVELOPE RETROFITTING

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## ABSTRACT

A major source of heat ingress in existing-buildings is through the envelopes. A bulk of cooling load in existing-buildings can be reduced by energy-efficient retrofitting of Roof, Walls and Fenestrations. The methods available for calculating heat ingress in large-scale existing structures are lengthy/cumbersome and manually impractical. The popular energy simulation software is black-box type requiring specialized technical skills, voluminous data-entries, several iterations and does not automatically select the most energy-efficient envelope retrofitting material out of available options in the local market. This paper proposes a user-friendly spread-sheet based model of a tool for automatically selecting energy-efficient envelope retrofit solutions from the available options.

## INTRODUCTION

### Importance of Energy Retrofits

The basic definition of 'building retrofit 'by David H Allen an American expert in energy-efficient building improvement, is the modification of the infrastructure of the building to improve its energy usage, comfort, safety, health and durability (Roy and Kiran Gupta, 2011). This could mean improving building components, building operating systems and equipment, and installing energy-efficient appliances. While the concept of constructing green buildings is now well established, retrofitting of existing buildings for energy efficiency is still a comparatively new concept in India. Retrofitting for energy efficiency has environmental, economic, social and regulatory benefits.

### Environmental Benefits

Buildings are responsible for more than 40 percent of global energy use and one third of global greenhouse gas emissions (GHG), both in developed and developing countries. The Building Sector has the largest potential for delivering long-term, significant and cost-effective reduction in greenhouse gas emissions. The main source of greenhouse gas emissions from buildings is energy consumption. While historically the majority of emissions emanated from developed countries, it is expected that in the near future the level of emissions from buildings in rapidly industrializing countries will surpass emission levels from buildings in developed countries (UNEP SBCI, 2009). Energy efficient retrofitting lowers the carbon footprint and green house gas emission by the buildings.

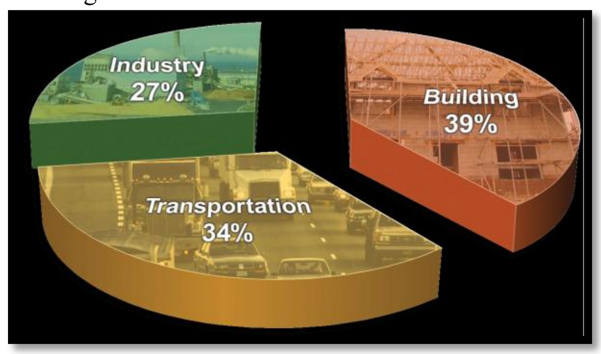


*Figure 1: Energy use in the US. (Source: DOE, 2010)*

### Economic Benefits

The main purpose of retrofitting for energy efficiency is to reduce energy consumption in buildings leading to lower operating costs. Rising fuel prices and energy crisis can lead to obsolescence of existing buildings with respect to its energy consumption even before their structural life span is over as they become too expensive to maintain. Knocking down the old structure and constructing new ones in busy areas is not easy. Demolition as well as construction can cause environmental hazards, cripple traffic movement and lead to down-time losses. An energy efficient improvement to an existing building increases its overall capital value & commands a higher rental value due to its prospects of reduced energy bills. A building with minimal running cost will attract and retain quality tenants and is preferred by investors in the property market. As per America Rebuilding program (Hendricks and Goldstein, 2009), building retrofits can cut energy use by 20 to 40 %. With proven techniques and off-the-shelf technologies, they can pay for themselves from the energy saved.

## Regulatory and Social Benefits

World over the Government regulatory agencies are gradually moving towards making the energy efficient environment protection norms in buildings mandatory (UNEP SBCI, 2009). An energy efficient retrofitted building will meet and comply with the energy and environmental performance demands of the future. The private sector under company social responsibility (CSR) is also switching over to demanding a minimum energy efficiency & environment performance level from the space they lease or procure. The private sector also perceives it as an opportunity to improve corporate image. Furthermore, large scale energy efficient retrofits will open new job opportunities and create market for construction sector.

# ENVELOPE ENERGY RETROFIT

The building envelope does not consume energy but significantly affects the energy use of mechanical and lighting systems. The energy and environmental benefits due to the implementation of retrofit actions in public buildings in Europe were investigated by Ardente et al., 2011. The results showed that the most significant benefits were from the improvement of envelope thermal insulation & applications. A classic example of an energy-wasting feature due to incorrect envelope selection is the use of all-glass façades with the expectation that highly efficient HVAC systems will somehow accommodate for the extravagant and inefficient design. In warm climates, the cooling loads and in cold climates, the heating loads in existing buildings are high. The envelope improvements and the control of solar heat gains result in significant reductions in energy use for cooling or heating.

Improvements to building envelope elements are generally referred as passive energy efficiency strategies. Building envelope improvements with the use of passive and low-energy techniques can bring in indoor comfort conditions within a total energy use of 100 kWh/m$^2$/year (Lam et al., 2008). This could place existing buildings in the same category as new buildings built today.

A building envelope is what separates the indoor and outdoor environments of a building. Various components such as walls, fenestration, roof, foundation, thermal insulation, thermal mass, external shading devices etc. make up this important part of any building. Several researchers around the world carried out studies on improvements in the building envelope and their impact on building energy usage. Energy savings of 31.4% and peak load savings of 36.8% from the base case were recorded for high-rise apartments in Hong Kong (Cheung et al., 2005) by implementing passive energy efficient strategies.

## Roof

Roofs are a critical part of the building envelopes that are highly susceptible to solar radiation and account for large amounts of heat gain / loss, especially, in buildings with large roof area such as sports complexes, auditoriums, exhibition halls etc. In accordance with the UK building regulations, the upper limits of U-value for flat roofs in 1965, 1976 and 1985 were 1.42W/m$^2$K, 0.6W/m$^2$K and 0.35W/m$^2$K, respectively. Currently, 0.25W/m$^2$K or less is required for all new buildings in the UK. This reduction in the U-value over the years emphasizes the significance of thermal performance of roofs in buildings (Sadineni et al., 2011). In the developing countries of South Asia and the Middle East, masonry houses with reinforced cement concrete (RCC) roofs are popular owing to their pest (termite) resistance, natural calamity (cyclones) resistance, availability and cost effectiveness of concrete ingredients. During tropical summers, they tend to exhibit unfavourable thermal characteristics such as high soffit temperature and long heat retaining capacity that affect the indoor air comfort conditions and increase cooling costs. The indoor temperatures exceed 40$^o$C due to high roof temperatures of about 65$^o$ C (Halwatura and Jayasinghe, 2008). This problem of high roof temperatures can be mitigated by employing roof shading, cool roof coatings or compound roof systems with a combination of radiation reflectors and thermal insulation. An insulated concrete roof system with an anti-solar coating proved successful in the tropical climatic conditions of Pakistan by reducing the roof heat gain in summers by 45kWh/day. The overall heat transfer coefficient of the roof was also reduced from 3.3W/m$^2$K to 0.54W/m$^2$K (Ahmad, 2010).

## Walls

Walls are a prominent faction of a building envelope and are expected to provide thermal and acoustic comfort within a building, without compromising the aesthetics of the building. The thermal resistance (R-value) of the wall is crucial as it influences the building energy consumption heavily, especially, in high rise buildings where the ratio between wall and total envelope area is high (Sadineni et al. 2011).

Conventionally, based on the materials used in construction, walls can be classified as wood-based walls, metal-based walls and masonry-based walls. There are other types of advanced building wall designs that are applied to improve the energy efficiency and comfort levels in buildings. Some of these are:

Walls with Thermal Insulation; Structurally Insulated Panels; Ventilated or Double Skin Walls; Passive Solar Walls; Light-Weight Concrete Walls; Walls With Latent Storage and Vacuum Insulation Panels.

## Glazed Fenestrations

Fenestration refers to openings in a building envelope that are primarily windows and doors. The fenestration plays a vital role in providing thermal comfort and optimum illumination levels in a building. They are also important from an architectural standpoint in adding aesthetics to the building design. A simulation study (Singh and Garg, 2009) was carried out on 10 different glazing types applied to five different climatic zones in India. It was observed that the annual energy savings by a window is dependent on not just the thermal conductivity (U-value) and the solar heat gain coefficient (SHGC value) but also on its orientation, climatic conditions and building parameters such as insulation level, floor area, etc. Following are the types of glazing materials and technologies that are aimed at providing high performance insulation, SHGC control and/or day-lighting solutions (Bahaj et al., 2008): Aero gel Glazing ; Vacuum Glazing; Switchable Reflective Glazing; Suspended Particle Devices Film; Holographic Optical Elements; Low Conductance Frames

## Motivation and Need for a Retrofitting tool

A wide variety of energy efficient retrofitting measures (EERMs) are available these days, making the selection of the right option difficult for the users. Heo et al. 2012, reiterate that building simulation software are more suitable for predicting energy use of yet-to-be-built projects, in which properties of the building and its systems parameters can be assumed to follow engineering design specifications. Existing buildings come with nuances associated with how buildings and their components are in actual and these are often difficult to represent in building energy models. Furthermore, the approach/methodology towards making an existing building into an energy efficient structure cannot be similar to a new construction. An existing building retrofitting usually has the following major constraints:

**An Already Existing Envelope; Budget Issues; Structural Issues; and Operational Issues.**

Australian Property Institute Reports (Newell et al., 2011), "Whether an organization would pursue a particular energy retrofit capital investment will depend on its priorities. Budget is an important issue as it may not fit in the normal maintenance allowance. The returns from the investment have to be attractive enough to convince the owners/tenants or investors to go for EERMs in buildings**.** Therefore an energy retrofit should offer several economically viable solutions for the users to choose from".

Given the above constraints in existing buildings and the various available measures for energy efficient retrofitting, there is a need to develop a technique / tool to find the best solution for energy efficient roof retrofitting of existing buildings. Several Simulation Tools are available for new building energy modelling and can be used for existing building simulation but require the user to have in-depth technical knowledge of thermal properties of materials, Building Science and Retrofitting options available in the market along with their costs/prices.

In most of the established simulation tools, the default climatic data is of the origin country and it is difficult for a non-technical user to place their own region's climatic data in the tool for correct simulation. These tools also require individual iterations of each retrofitting option which is time consuming. The retrofitting results in these models can facilitate in decision making for selection of right energy retrofit solution only after the technically knowledgeable user has accurately provided all input data, which run in more than 100 items. The right thermal properties of the local existing building envelope, market availability of retrofitting material along with current prices are important pre-requisites to find the best retrofitting option. The data for these regional pre-requisites are not inbuilt in the available tools. Most of these simulation tools are also expensive and beyond the reach of a common man in India and other developing nations.

Zhenjun Ma et al. 2012, in their paper "Existing Building Retrofit: Methodology and State of Art", concludes that "building retrofit with comprehensive energy simulation & economic analysis is an effective approach to identifying the best retrofit solutions but further research work and investigation in this regard are needed to facilitate cost effective building retrofits".

Lizana et al. 2016, in their assessment of methods for energy retrofit, describes that "the selection of the correct method and variables to identify the most effective retrofit solutions is still a technical challenge".

The prescriptive recommendations of local codes may not be accurate as the performance and selection of an EERM is a multi-objective decision problem, the constraints being Existing Construction Type, Climatic Region, Occupancy Type, Building Byelaws, Market Availability, Cost of EEMs, Budget and Client Priorities.

This paper proposes a simple user–friendly decision tool for obtaining energy retrofit solutions. The tool takes minimum number of easy building parameters, proposes options for technical ones and simultaneously suggests energy retrofit solutions for the Existing Roof, Walls and Glazed Openings from a predetermined list of market available EEMs. The results are displayed immediately after the user inputs the building data, thereby saving time and effort. The goal of this tool is to facilitate and promote energy saving retrofits.

## OBJECTIVE OF TOOL DEVELOPMENT

The Tool has been developed on the commonly available MS-Excel spread-sheet platform to select the most suitable Energy Efficient Retrofitting Measures (EERMs) for the roof, wall and glazed opening systems of an existing building. Presently the focus is on reduction of cooling load which is predominant in tropical climates covering over more than 80% of Indian land area. Developed model would be utilized to finalize the EERMs to improve thermal performance of an air-conditioned building, where the aim is to reduce the annual plant cooling load. This tool would automatically assess the viable energy efficient alternatives for retrofitting a building to arrive at the envelope retrofitting solutions under the followings formats:

1. Solution with Minimum Initial Cost
2. Solution with Maximum Energy Efficiency
3. Solution with Maximum Net Present Value (NPV)
4. Solution with Minimum Life Cycle Cost

The user can select their preferred option based on their need, priority or affordability.

## METHODOLOGY TOOL DEVELOPMENT

### Objective Function for the Tool

Thermal Properties of Existing envelope construction materials, maximum energy efficiency and cost of EERMs are the most important constraints for decision making. The Objective function for the Tool in air-conditioned building would be:

Minimization F(x) = Cooling Load

Maximization F(y) = Net Present Value (NPV)

At First, the effort was to find out various energy efficient roof, wall & glazed opening retrofitting materials available in the market that could be applied to existing buildings with the aim towards reducing the use of energy and thereby minimizing the air-conditioning load. Secondly, the focus was on developing a user friendly Excel Spread Sheet based tool to help in selection of the right EERMs for Existing Building Roofs, Walls & glazed openings in the three climatic zones of India.

### Climatic Zones of India

The figure 2 shows the five different climatic zones of India. Each climatic zone needs its own design criteria on the building envelope in order to make the indoors comfortable. Presently, for the purpose of this tool development the weather conditions of three climatic zones i.e. Hot & Dry, Hot & Humid and Composite climatic zones have only been considered. These climatic zones cover more than 80% of Indian Territory (Bansal and Minke, 1995).

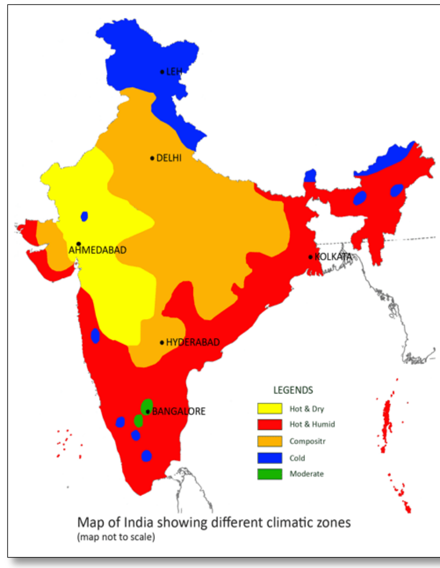


*Figure 2: Climatic Zones of India*

### Principles of CIBSE Admittance Method

The CIBSE admittance method has been used for determination of thermal load of existing buildings. Cooling load has been primarily considered. In case of CIBSE Admittance method linear heat transfer and fluctuating temperature can be handled independently to evaluate their effect separately and summed up to obtain the overall effect of steady periodic temperature variations (CIBSE, 1998). Both external and internal mean remain constant throughout the seasons, i.e. they can be assumed as time invariant. Thus, principles of steady state heat transfer can be applied to the mean. Similarly, effect of external solar radiation, ventilation heat transfer, casual heat gain etc. can also be handled treating them as steady periodic variation. In case of steady periodic variation with mean and a fluctuation, these means again remain constant with time as per the principles of steady state heat transfer (Clarke, 2001).

Assuming net heat transfer in a steady state case is equal to zero, i.e. sum of heat transfers due to constant external and internal mean temperatures, constant mean radiation heat, constant mean ventilation heat and constant mean casual heat gain is equal to zero. One can obtain the unknown internal mean temperature when rest all variables in the steady state heat transfer are known. To deal with the fluctuating components, transmission matrix solution of transient heat conduction equation is used (Pipes 1957).

To estimate the fluctuating components of the internal temperature variation, decrement response factor and admittance response factors are defined.

Similarly, the effect of fluctuating component of direct radiation heat gain through the glasses and opaque surfaces, fluctuating component of casual heat gain and fluctuating component of ventilation heat transfers are considered. It is assumed that net periodic heat transfer in 24 hour cycle is again zero as temperature variations are steady periodic, i.e. repeats itself after every 24 hour cycle. Thus, one can estimate the fluctuation of inside temperature above its mean. Summing up this fluctuation with internal mean gives the actual inside temperature as a function of time. (CIBSE 1998).

**Steady State of Heat Flow**

In steady state, the algebraic sum of various heat transfer modes, i.e. conduction heat gain/loss through opaque surfaces, effect of solar radiation through opaque surfaces, conduction heat gain/loss through transparent surface, radiation heat gain/loss through transparent surface, heat gain/loss through ventilation and casual heat gain from people, lighting and equipments is equal to zero. Following are the Steady State Heat Flow Equations used for Developing the Tool:

$Q_{cdm} + Q_{cdmI} + Q_{gc} + Q_{dIm} + Q_{mcv} + Q_{mC} = 0$ ……………. (1)

$Q_{cdm} = (T_{mo} - T_{mi}) \sum_{j=1}^{n} U_j A_j$ = Conduction heat gain or loss through opaque surfaces……….….. (2)

$Q_{cdmI} = \sum_{j=1}^{m} U_j A_j \frac{\alpha_j I_{mj}}{h_{oj}}$ = Heat gain or loss through opaque surfaces due to radiation…………………… (3)

$Q_{gc} = (T_{mo} - T_{mi}) \sum_{k=1}^{n} U_j A_j$ = Conduction heat gain or loss through transparent surfaces………………... (4)

$Q_{dIm} = \sum_{j=1}^{n} A_j I_{mj} \theta_{mj}$ = Radiation heat gain or loss through transparent surfaces ………………………. (5)

$Q_{mcv} = \frac{1}{3} N V_R (T_{mo} - T_{mi}) = C_{mv}(T_{mo} - T_{mi})$ = Heat gain or loss through ventilation……………… (6)

$Q_{mC} = \sum_{j=1}^{p} Q_{mCj}$ = Casual heat gain or loss from people, lighting and equipment…………………….. (7)

where *j* and *k* indicates the particular opaque and transparent surface respectively, *m* and *n* are the total number of exposed opaque and transparent surfaces respectively, *U* is the U-value ($W/m^2K$), *A* is the surface area ($m^2$), α is the absorptivity of the surface, θ is the solar gain factor, $T_{mo}$ is the mean external temperature (K), $T_{mi}$ is the daily mean internal environmental temperature (K), $I_{mj}$ is the mean solar radiation on particular surface ($W/m^2$), $h_o$ is the convective heat transfer coefficient for outer surface, *N* is the number air changes , *V* is the volume of enclosure ($m^3$), $C_v$ is the ventilation conductance (W/K), *p* is the total number of casual sources. By solving the above equations daily mean internal temperature $T_{mi}$ is obtained.

$T_{mi} = T_{mo} + \frac{Q_T}{\sum_{j=1}^{n} U_j A_j + C_{mv}}$ ………………………………………… (8)

Where, $Q_T = \sum_{j=1}^{m} U_j A_j \frac{\alpha_j I_{mj}}{h_{oj}} + \sum_{j=1}^{n} A_j I_{mj} \theta_{mj} + \sum_{j=1}^{p} Q_{mCj}$ ………………………………………… (9)

$T_{ia}$ room temperature inside at any time (t) is the sum of mean and fluctuating component $T_{fi}$ (t):

$T_{ia}(t) = T_{mi} + T_{fi}(t)$ ……………………………… (10)

**Fluctuating Component of Heat Flow**

Second part of admittance procedure is the fluctuating component of heat flow. The response to fluctuating loads is determined mainly by material characteristic known as the admittance of a surface (which is essentially a dynamic U-value), decrement response factor and their thermal lag, to define their dynamic response. The admittance and decrement response factors are functions of the thickness, thermal conductivity, density and specific heat capacity of each of the materials used within a construction, as well as the relative positions of those materials (CIBSE 1998).
A square matrix, known as overall transmission matrix is used to calculate values of the factors. The overall transmission matrix provides fundamental relationship between temperature and flux at inside and outside surfaces of a roof (Pipes 1957). The fluctuating component $T_{fi}$ is expressed in equation as:

$T_{fi}(t) = \frac{Q_{fi}(t)}{\sum AY + C_{mV}}$ ……………………………………………………(11)

where

$Q_{fi}(t) = \sum_{j=1}^{n} \mu_j U_j A_j [T_{oa}(t - Ø_j) - T_{mo}] + \sum_{j=1}^{m} \mu_j A_j \frac{\alpha_j I_{fi(t-Øj)}}{h_{oj}} + \sum_{j=1}^{l} A_j I_{fi}(t) \theta_j + C_{mV} + T_{fo}(t) + \sum_{j=1}^{l} m_j Q_{fCj}(t)$ ……………………(12)

where, $Ø_j = Ø_{dj} + Ø_{Yj}$ ……………………………(13)

**Calculation of Annual Hourly Plant Load**

The admittance method is also used for the estimation of air conditioning plant capacity to maintain constant air temperatures in buildings(Clarke 2001). To calculate annual hourly plant (heating and cooling) load, mean component and fluctuating component of the load are added (CIBSE, 1998). For the hourly basis daily analysis, 24 equations can be obtained from the following equation:

$Q_L(t) = (-) \{[\sum_{j=1}^{n} U_j A_j + C_v(t)]_{\Delta T} + \sum_{j=1}^{m} U_j A_j \frac{\alpha_j I_{mj}}{h_{oj}} + \sum_{j=1}^{n} A_j I_{mj} \theta_{mj} + \sum_{j=1}^{p} Q_{mCj} + C_{mv}(t) T_{fo}(t) + \sum_{j=1}^{n} \mu_j U_j A_j [T_{oa}(t - Ø_j) - T_{mo}] + \sum_{j=1}^{m} \mu_j A_j \frac{\alpha_j I_{fi(t-Øj)}}{h_{oj}} + \sum_{j=1}^{l} A_j I_{fi}(t) \theta_j + \sum_{j=1}^{l} m_j Q_{fCj}(t)\}$

For (t) = 1, 2, 3… 24 ………………………..… (14)

## Process Algorithm Energy Retrofit Tool

The detailed working process of the tool has been displayed in the following process flow chart:

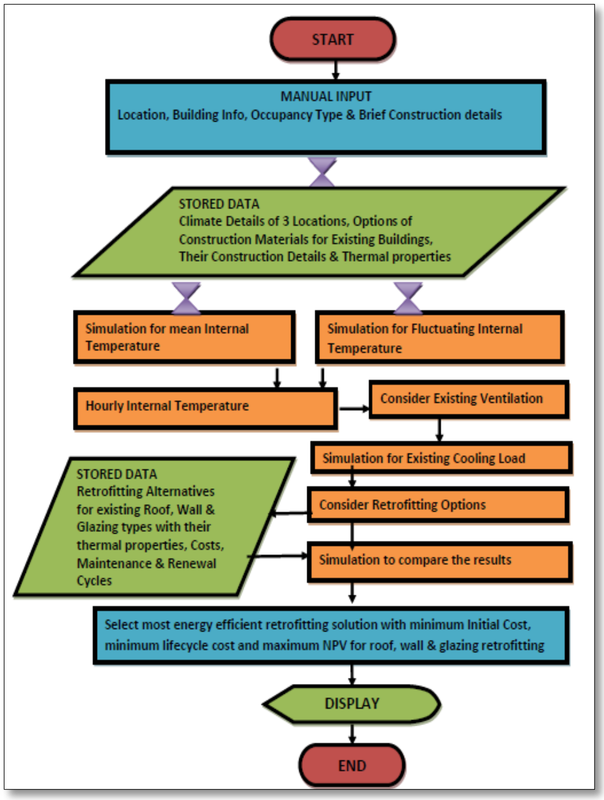


*Figure 3: PROCESS FLOW CHART*

## Assumptions from Existing Construction

There are some general construction materials and details followed in the existing buildings of India. Some standard construction details which have been used over the last 30 years have been assumed as the options for the standard base case scenario for retrofitting purposes. The construction details of the same have been referred from the Central Public Works Department's Delhi Schedule of rates (DSR) for the year 1997 (GOI, 2007). For the purpose of the tool, all Roofs are assumed to be flat only, The occupancy and air change guidelines have been referred from SP41(Bureau of Indian Standards, 1987), Roof Area is calculated on the basis of Building Byelaws laid in Delhi Master-plan 2021 (Delhi Development Authority 2007), and All Buildings are assumed to be Air-Conditioned. Out of the Energy Retrofitting Items Available in India as per DSR2016 (Central Public Works Department, 2016) around 40 alternatives of compound roofing systems, 34 combinations of compound walling systems and 4 types of glazed fenestration systems were considered and computed for decision tool. Wall options were restricted to only those with a maximum 50mm addition in the external walls.

***Table 1: Existing Roof Types in India***

| Type | **Typical Existing Roof Construction Layers (outside to inside)** *References: CPWD DSR 1997,* |
|---|---|
| 1 | Roof Finished with 40mm Cement Concrete flooring + 100mm RCC+ 12 mm CPL |
| 2 | Painting Roof Tops with 12mm thick bitumen mixed with a coat of coarse sand + 100mm RCC+ 12 mm CPL |
| 3 | 50 mm Flat Brick Tiles + 12mm cement mortar mixed with water proofing compound + 100mm RCC+ 12 mm CPL |
| 4 | 50 mm Flat Brick Tiles + 12mm cement mortar mixed with water proofing compound + Painting Roof Tops with 12mm thick bitumen mixed with a coat of coarse sand + 100mm RCC+ 12 mm CPL |
| 5 | 50 mm Flat Brick Tiles + 12mm cement mortar mixed with water proofing compound + 25mm mud mortar mixed with bhusa (@35kg per cum earth and gobri leaping) +100 mm mud phaska + 100mm RCC+ 12 mm CPL |
| 6 | 20mm Pressed Clay Tiles + 20mm cement mortar +100mm RCC+ 12 mm CPL |
| 7 | 40mm thick Stone chips Terrazzo Flooring + Painting Roof Tops with 12mm thick bitumen mixed with a coat of coarse sand + 100mm RCC+ 12 mm CPL |
| 8 | 30mm thick Crazy Marble Stone Flooring + Painting Roof Tops with 12mm thick bitumen mixed with a coat of coarse sand + 100mm RCC+ 12 mm CPL |
| 9 | 20mm Precast Terrazzo Tiles with marble chips + 30mm bed of ordinary cement mortar + Painting Roof Tops with 12mm thick bitumen mixed with a coat of coarse sand + 100mm RCC+ 12 mm CPL |
| 10 | 25mm Kota Stone Flooring + 20mm bed of ordinary cement mortar + Painting Roof Tops with 12mm thick bitumen mixed with a coat of coarse sand + 100mm RCC+ 12 mm CPL |
| 11 | 100mm Lime Concrete + Painting Roof Tops with 12mm thick bitumen mixed with a coat of coarse sand + 100mm RCC+ 12 mm CPL |

*RCC: Reinforced Cement Concrete, CPL: Cement Plaster*

***Table 2: Existing Wall Types in India***

| Type | **Typical Existing Wall Construction Layers (outside to inside)** *References: CPWD DSR 1997* |
|---|---|
| 1 | 230 mm Exposed Brickwork + 12 mm CPL |
| 2 | 12 mm CPL + 230 mm Brickwork + 12 mm CPL |
| 3 | 15 mm Washed Grit Plaster +12 mm CPL + 230 mm Brickwork + 12 mm CPL |
| 4 | 40 mm Red Sand Stone +12 mm Cement Mortar + 230 mm Brickwork + 12 mm CPL |
| 5 | 40 mm Dholpur Stone +12 mm Cement Mortar + 230 mm Brickwork + 12 mm CPL |
| 6 | 300 mm Ashlar Masonary Work + 12 mm CPL |

***Table 3: Existing Openings Types in India***

| Type | **Typical External Openings Types Existing in India** *References: CPWD DSR 1997* |
|---|---|
| D1 | Panelled Wooden Door Shutter 40 mm Thick |
| D2 | Flushed Door Shutter 35 mm Thick |
| D3 | 4mm Thick Glazed Door in Wooden Frame |
| D4 | 4mm Thick Glazed Door in Steel Frame |
| W1 | 4mm Thick Glazed Window in Wooden Frame |
| W2 | 4mm Thick Glazed Window in Steel Frame |

## ENERGY RETROFIT DECISION TOOL

The tool has been developed on the MS Excel spread sheet platform without using macros. The basic details of the existing building data are fed by the user in a simple "INPUT FORM" which is linked to several stored data and simulation sheets as displayed in the "Figure 3". The simulation of data based on CIBSE admittance method occurs simultaneously as soon as the related building information is filled and selected by the user in the 'INPUT FORM'.

***Table 4: A Screen-Shot of the "INPUT FORM"***

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | DECISION TOOL FOR ENERGY EFFICIENT RETROFITTING | | | | | | | | | |
| | INPUT FORM | | | | | | | | | |
| | PROJECT NAME | SHANGRILA HOTEL , NEW DELHI | | | | | Building Age (Years) | | | 12 |
| | SELECT LOCATION | "Delhi" | | | | | Average Energy Cost Per Unit | | | ₹ 8.40 |
| | BUILDING TYPE | HOTEL | | | | | | | DATE | 31/01/18 |
| A | FILL EXISTING BUILDING GENERAL INFORMATION | | | | | | | | | |
| | Plot Area (Sqm) | 2450 | No.of Stories (above Plinth Level) | | | 17 | Plinth Height (Btw 0.6 m-1.5 m) | | | 0.9 |
| | Covered Area on All Floors (Sqm) | 18620 | Floor to Floor Height (Between 2.9 m and 5 m) | | | 4 | No.of Stories below Ground Floor (Basements) | | | 2 |
| | Building Lengths in Metres (m) | Wall Facing | North | South | East | West | North East | South East | North West | South West |
| | | Length | 0 | 0 | 0 | 0 | 42 | 42 | 42 | 42 |
| B | FILL EXISTING BUILDING ENVELOPE INFORMATION | | | | | | | | | |
| 1 | Select Existing Roof Surface Construction (From Outside to Inside) | | Roof Finished with 40mm Cement Concrete + 100mm RCC+ 12 mm CPL | | | | | | | |

The energy efficient retrofitting solutions recommended by the tool are displayed in the "OUTPUT SHEET" as soon as the building data is fed in the Input Form.

Based on the user concerns discussed earlier, the recommendations for roof retrofitting by the model are in the followings formats:

1. Solution with Minimum Initial Cost
2. Solution with Maximum Energy Efficiency
3. Solution with Maximum NPV
4. Solution with Minimum Life Cycle Cost

The user can select their preferred option based on their need, priority or affordability. The initial cost of the retrofitting solutions is based on the prevalent rates of the composite items as per DSR2016 (Central Public Works Department, 2016). Since the purpose of the cost analysis is to compare the retrofitting options, therefore cost of common elements like taxes has been avoided.

## Tool Application on the Case Study

The developed tool is being used to find the EERMs for a 5-Star hotel in Delhi. This project was built in 2003 without any energy efficiency perspective in its design brief. The building is 17 storied with several glass windows all over the façade with ample scope for energy savings. The "Table No.4" above shows the screen-shot of the few simple building information like location, area, number of stories, size and location of the windows etc. of the hotel which were the manual input on the Tool Input Form.

***Table 5: A Screen-Shot of "OUTPUT SHEET"***

| | | | | | |
|---|---|---|---|---|---|
| | RECOMMENDATIONS FOR ENERGY EFFICIENT RETROFITTING | | | | |
| 4 | ROOF RETROFITTING SOLUTIONS | | | | |
| | EXISTING ROOF CONSTRUCTION TYPE | MINIMUM INITIAL COST | MOST ENERGY EFFICIENT | MAXIMUM NET PRESENT VALUE | MINIMUM LIFE CYCLE COST |
| | Roof Finished with 40mm Cement Concrete + 100mm RCC+ 12 mm CPL | Two coats of High Albedo white reflective paint + 10mm Bitumen Layer + Existing Roof | Green Cover + 150 mm soil layer + 1.25 mm geo textile layer+ 40 mm cement concrete + 15mm APP bituminous membrane+ Existing Roof + 100mm RCC+ 12 mm CPL) + 50mm EPS +12mm calcium silicate board (or Gypsum board) | 40 mm cement screed + 40 mm PUF Insulation + Existing Roof | 6 mm Crazy Ceramic Tile Flooring + 12 mm cement mortar + Existing Roof |
| i | Roof Heat Gain Reduction(%) | 84% | 98% | 89% | 68% |
| ii | Roof Retrofitting Cost | ₹ 350,840 | ₹ 2,072,288 | ₹ 1,127,980 | ₹ 467,460 |
| iii | Maintenance Cost (Building life-time) | ₹ 2,282,812 | ₹ 3,693,644 | ₹ 214,316 | ₹ 88,817 |
| iv | NPV (30 years loan period ) | ₹ 1,150,204 | ₹ -1,217,959 | ₹ 2,619,212 | ₹ 2,451,628 |
| v | Annual Savings in Energy Cost | 132,769 | 155,974 | 140,964 | 107,674 |

The "Table 5" above shows the screen-shot of the roof retrofit recommendations by the tool for the case study hotel based on stored climatic data, material properties and inbuilt computation process based on CIBSE admittance procedure. Similarly 4 recommendations each were also proposed by the tool for the energy retrofit of wall and glazing. The simulation process was immediate and gives the users the energy efficiency, initial and maintenance costs, NPV and Annual Savings for all four EERMs, from which the user can choose one based on their need, priority or affordability. The tool is very user friendly and can be used by anyone who has basic knowledge of MS Excel.

## Tool Validation with eQUEST

The energy performance of the case-study existing building and retrofitted alternatives were evaluated using eQUEST and compared to the results obtained through the developed tool. Energy Efficiency Ratios (EER) of Each of the 40 compound roofing systems, 34 combinations of compound walling systems and 4 types of glazed fenestration systems were calculated individually on the eQUEST platform and their EER compared to the EER of the same alternatives obtained by using the tool. The peaks of energy efficiency and results profile as shown in the Figures 4, 5 & 6 were found to be similar. The most energy efficient envelope retrofit solutions were also the same. The results cannot be compared on absolute terms as the eQUEST simulation is for the calculation of the whole building energy loads including default parameters for active cooling / heating controls. Furthermore, the thermal properties of the decision tool are based on SP41 (Bureau of Indian Standards, 1987) the values for which are slightly different from the eQUEST inbuilt values. The range of error between the two results was found to be less than the prescribed range of (+) (-) 40% as estimated by the Industry experts for energy models accuracy ranges (Clevenger and Haymaker 2001). The eQUEST results validate the results of the developed Decision Tool. Furthermore, it is important to note that the tool gave same results within seconds of data input in comparison to the several time consuming iterations on eQUEST.

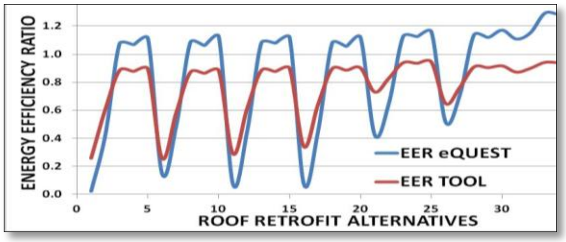


*Figure 4: Roof ERMs Performance Comparison*

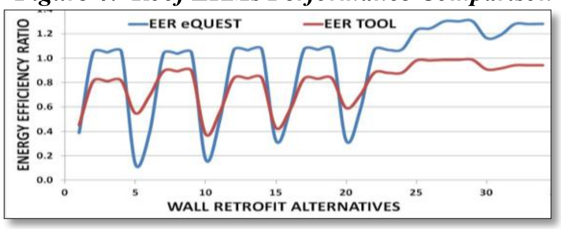


*Figure 5: Wall ERMs Performance Comparison*

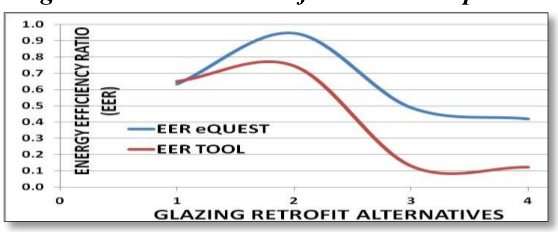


*Figure 6: Glazing ERMs Performance Comparison*

## CONCLUSIONS

The above validation confirms that the developed energy-retrofit tool is a workable model of an instrument to find the most energy efficient retrofit solution for roof, wall and glazed fenestrations. Since this tool has been developed on a commonly available spread-sheet platform MS Excel with simple user input, it can be used widely by masses having no access or know how to use specialized software. All tool users including Architects, Engineers, Builders and Developers can select the best market available EERM based on their need, priority or affordability from amongst the four retrofit solutions proposed by the tool under the yardsticks of Minimum Initial Cost, Maximum Energy Efficiency, Maximum NPV and Minimum Life Cycle Cost. Presently the tool has been developed for three climatic zones of India, however with minimal changes in the stored data of climate, existing buildings and available EERM material properties with their costs, the tool can be easily edited and modified for use in any other country. The goal of this tool is to promote energy saving retrofits.

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