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Cost benefits of Utilizing Thermal Insulation in Residential Complexes and a Comparative Study between Insulated buildings and MIVAN Projects

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Abstract: The residential sector in India is rapidly increasing given the expanding population of the middle class[1]. An estimated 600 Mn people are likely to be living in urban centers by 2030, creating a demand for 25 Mn additional mid-end and affordable units. To meet this demand construction technology MIVAN is in use, but, due to the use of dense concrete for wall construction, it doesn't meet the sustainability standards for green buildings set by the Eco Niwas (The Residential Energy Conservation Building code). Given the country's hot, dry, and composite environment, effective thermal insulation is crucial for sustainability and energy efficiency. Through the use of case study simulation, this work investigates the law of diminishing returns while enhancing the conservation level of residential structures. In this study, I identify the optimal thickness of Fiberglass insulation with 24 Kg/m density and 0.033 K conductivity value applied on 200 mm thick, 64m^2 concrete walls constructed using MIVAN technology. The RETVs (Residential Envelope Transmittance Value) of the dwelling unit with and without the insulating material have been calculated to identify which one meets the sustainability, and energy-efficient criteria. In addition, the cost-benefit of applying insulation to the growing middle class of India by finding out the pay-back period and return on investment. This research finds that using insulation in residential units will promote sustainable development and be cost-effective.

Index Terms – **Sustainable dwelling unit, Thermal Insulation technology, Insufficient MIVAN construction technology, Cost-Effective green residence**

INTRODUCTION

India is a South-East country with a population of about 140.76 crores. An estimated 600 Mn people are likely to be living in urban centers by 2030, creating a demand for 25 Mn additional mid-end and affordable units. Thus, the country is adopting fast and effective construction technology called MIVAN technology.

Since L&T used MIVAN technology for the first time in India in 2003, the technology has been widely adopted in the country with a growing need for faster construction. It is an aluminum formwork system used in residential and mass housing projects due to its strength, durability, adaptability, and ease of installation. This technique uses dense concrete as the building material. After casting the forms, high-quality concrete is poured. This concrete takes the form and shape of the cast. This process of using dense concrete to construct walls and roofs of a built space makes the MIVAN-constructed buildings highly heat-conductive and uncomfortable to live in, especially in the composite, and hot and dry climatic conditions of India.

MIVAN-constructed buildings consume a huge amount of electrical energy in the summer months due to the usage of Air Conditioning for long durations to bring the temperature inside the dwelling unit to a comfortable temperature. This hinders NITI AAYOG from achieving the Sustainable Development Goals by 2030. The construction technology is inconsistent with Goal 11, making cities and human settlements inclusive, safe, resilient, and sustainable, Goal 12, ensuring sustainable consumption and production patterns and Goal 13, taking urgent action to combat climate change and its impacts. Hence, there is a pressing need to adopt MIVAN construction technology with such a technology that will keep out excessive heat and thus, maintain optimal temperature inside the dwelling unit and save electrical energy.

Thermal Insulation fits the bill. It is a material of relatively low heat conductivity used to shield a volume against loss or entrance of heat by radiation, convection, or conduction. Insulation is widely used in walls, roofs, floors, and attics of residential, commercial, and industrial buildings. For this study we select Fibrous Insulation called Fiberglass with 24 Kg/m density and 0.033 K conductivity value.

RESEARCH METHODOLOGY

[1] The middle class is the fastest-growing major segment of the Indian population in both percentage and absolute terms, rising at 6.3 percent per year between 1995 and 2021. It now represents 31 percent of the population and is expected to be 38 percent by 2031 and 60 percent in 2047.

3.1 Case Study Simulation

Dwelling units, each in two climatic conditions of India- composite and, hot and dry. It has 64 m^2 walls constructed with 200 mm concrete. One wall has a single glass pane window constructed occupying 20 % of the wall. Degree day calculation says that the lifecycle of a house is 30 years. The cost of Energy consumed by the unit is the cost of running an Air Conditioning here in the summer months between April to July, for 14 hours, accrued over this period.

3.2 Data Sources

All data sources are Secondary Data, taken from Documents released, or authorized by the Government of India.

1. Data taken from NOAA (National Oceanic and Atmospheric Administration) to calculate Temperature Difference.
2. The cost of one unit of electricity (kwH) is 6.5 Rs 9 (Appx), according to the Delhi Electricity Regulatory Commission (DERC)

3.3 Calculation Procedure

1. Calculation of Temperature Difference

Place	Climate	Average Temperature in April (Highest temp. +Lowest temp./2)	Average Temperature in May (Highest temp.+ Lowest temp./2)	Average Temperature in June (Highest temp. +Lowest temp./2)	Average Temperature in July (Highest temp. +Lowest temp./2)	Average external Temperature= (Sum of avg. temp. from April to June/4)	Optimal Internal Temperature	Temperature Difference
New Delhi	Composite	(37+21)/2=29	(40+26)/2=33	(39+28)/2=33.5	(35+27)/2=31	31.6	24	7.6
Jaipur	Hot and Dry	(41+26)/2=38.5	(39+26)/2=32.5	(39+27)/2=33	(34+25)/2=29.5	33.4	24	9.4

**Data taken from NOAA (National Oceanic and Atmospheric Administration)*

The buildings in the hot and dry, and Composite climatic conditions in India require a cooling effect to bring internal temperature to a thermally comfortable temperature, especially during summer.

Two cities having particular climatic conditions have been chosen- New Delhi for composite conditions, and Jaipur for hot and dry conditions.

To calculate the optimal temperature difference between the external and internal environments, the average temperature has been calculated for each month between April and July.

Then, the average temperature during summer has been calculated by finding the sum of the Average temperatures during each month from April to July and dividing it by four.

The optimal room temperature has been assumed to be 24 degrees Celsius which is the default setting of an Air Conditioner.

Finally, The Temperature difference is calculated for each climatic condition.

2. Dimensions of Assumed Room

Let it be a cubical room with the complete wall area being 64 m^2.

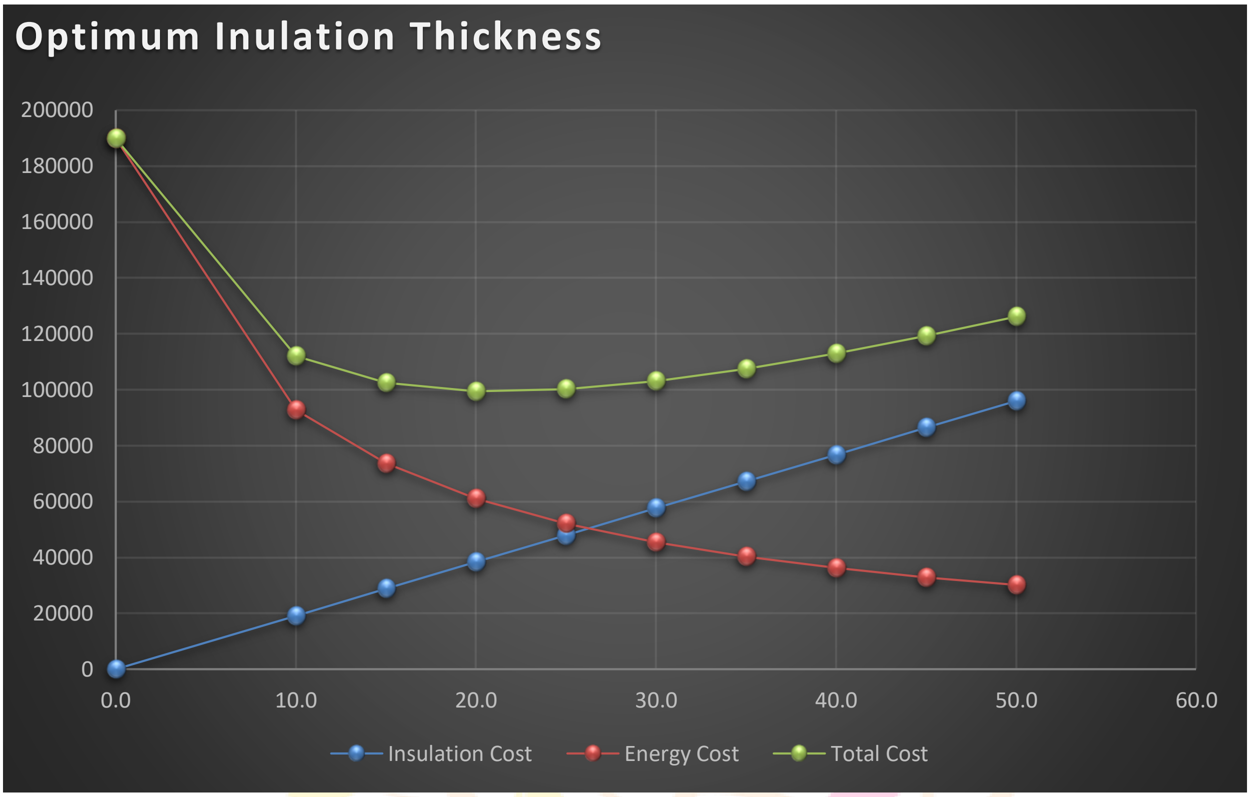
Let the room have a single-glass pane window that occupies 20 percent of the wall area.

3. Calculation of the optimal thickness of insulation

The Equilibrium point is found using the law of Diminishing Returns.

3.1 In Composite Weather Condition

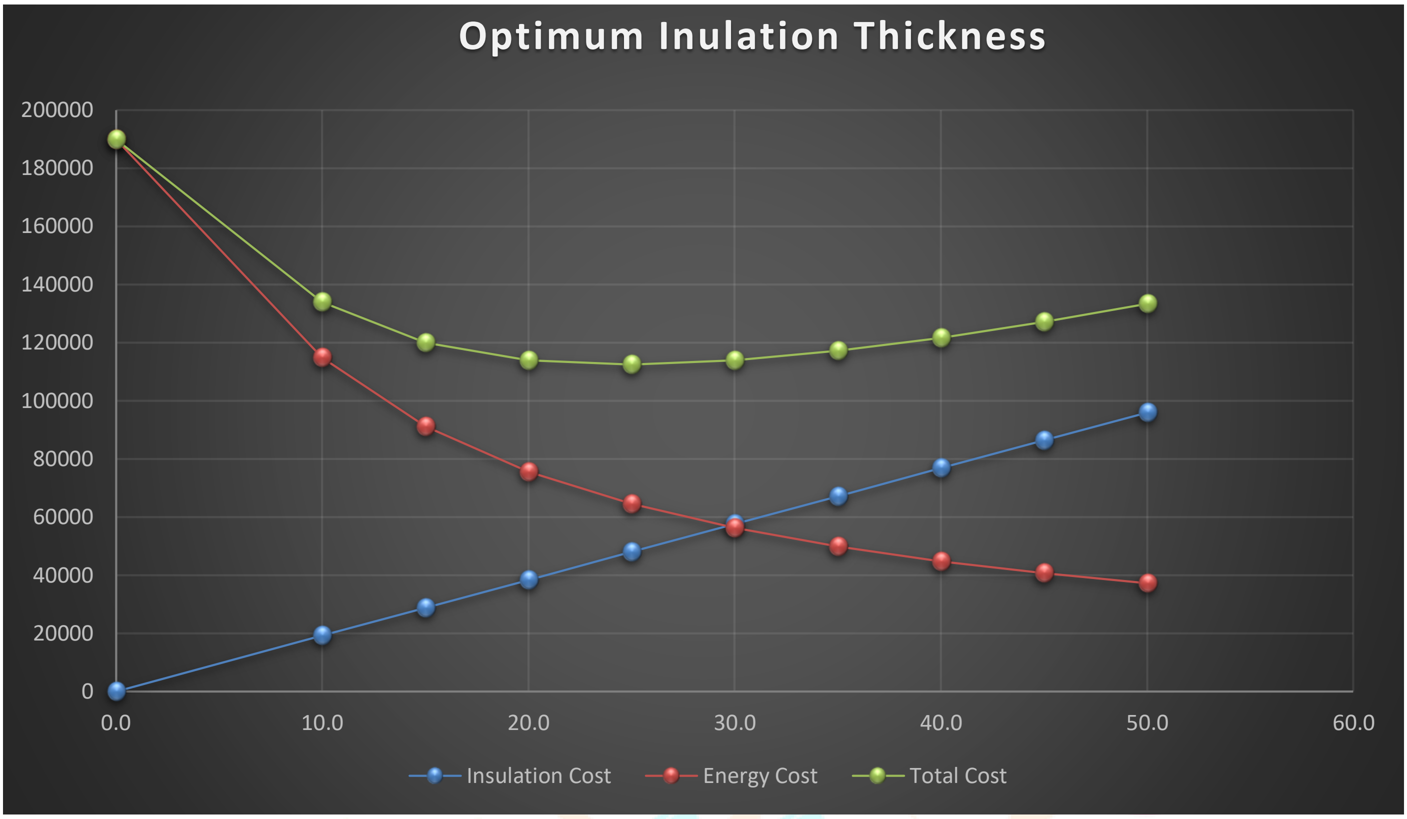
Thickness of insulation	Insulation Cost	Energy Cost	Total Cost
0.0	0	189828.6	189828.6
10.00	19200	92774.39	111974.39
15.00	28800	73637.76	102437.76
20.00	38400	61045.8	99445.8
25.00	48000	52131.4	100131.4
30.00	57600	45488.77	103088.77
35.00	67200	40347.63	107547.63
40.00	76800	36250.59	113050.59
45.00	86400	32908.91	119308.91
50.00	96000	30131.32	126131.32



The graph shows that the ***optimal thickness of the insulation*** is 20 mm.
Cost Saving= 67.8%
Pay-back Period= 19 Years(Apprx): Cost of Energy Consumption in one year/ Investment in Insulation
Return on Investment= 22,383.46 Rs.

3.2 In Hot and Dry Weather Conditions

Thickness of insulation	Insulation Cost	Energy Cost	Total Cost
0.0	0	189828.6	189829
10.00	19200	114747.27	133947
15.00	28800	91078.28	119878
20.00	38400	75504.02	113904
25.00	48000	64478.31	112478
30.00	57600	56262.42	113862
35.00	67200	49903.65	117104
40.00	76800	44836.26	121636
45.00	86400	40703.12	127103
50.00	96000	37267.68	133268



The Graph shows the ***thickness of optimal insulation*** is 25mm
Cost Savings*= 66%*
Payback Period= 22.3 yrs: Cost of Energy Consumption in one year/ Investment in Insulation
Return on Investment= 17,194.21 Rs.

Calculation of insulation cost

The cost of 50mm thick of insulation is 1500Rs. (According to market rate)
Therefore, the cost of 1mm thick insulation = 30Rs[2]
Cost of insulation= Cost of 1mm thick insulation*Thickness of Insulation

Calculation of Energy Cost

R-Mivan	Thickness	R-Insulation	R-internal	R-external	Total R	U-value	Cooling load	Cost
0.11	0.01	0.303030303	0.13	0.04	0.58	1.71518	0.278552	92774.39
0.11	0.015	0.454545455	0.13	0.04	0.73	1.36139	0.221095	73637.76
0.11	0.02	0.606060606	0.13	0.04	0.89	1.12859	0.183288	61045.80
0.11	0.025	0.757575758	0.13	0.04	1.04	0.96379	0.156523	52131.40
0.11	0.03	0.909090909	0.13	0.04	1.19	0.84098	0.136578	45488.77
0.11	0.035	1.060606061	0.13	0.04	1.34	0.74593	0.121142	40347.63
0.11	0.04	1.212121212	0.13	0.04	1.49	0.67019	0.108841	36250.59
0.11	0.045	1.363636364	0.13	0.04	1.64	0.60841	0.098808	32908.91
0.11	0.05	1.515151515	0.13	0.04	1.80	0.55706	0.090468	30131.32

I R-Value Calculation

R-Value= Thickness of material/ Conductivity of material

R-Mivan

Thickness (L in m)	Conductivity (K in W/m.K)	R-wall (m2.K/W)
0.2	**1.74**	**0.11**

R-Insulation

The thickness of insulation/ 0.033 W/m.K

II U-Value Calculation

[2] See: Rate on Indiamart- https://www.indiamart.com/proddetail/fiberglass-wool-insulation-24kg-25mm-thk-23203190433.html

1/ Total R-Value
Total R-value= Internal R-value+ External R-Value+ R-Wall+ R-Insulation = 0.04+0.13+0.11+ R-Insulation

III Cooling Load

To calculate the Cost of Energy consumption, we need to calculate the heat load and the cooling requirement.

1. Heat load of room (KW): Heat load can be defined as the amount of temperature that can be added to a space to reach an acceptable range of energy. Eq= Area of room(m^2) * Temperature difference(K) * U-value(W/ m^2.K)

2. Cooling Load: the amount of heat that can be removed from a space to maintain an acceptable range of energy is called a cooling load.

Eq= Heat load/ EER.

Calculation of EER (Energy Efficiency Coefficient): Assuming a 3-star Window AC. The Average of, minimum EER and maximum EER=(2.90 + 3.09)/2= 2.995 W

IV Cost Calculation

The cost of one unit of electricity is 6.5 Rs

We calculate the cost of electricity consumed by the dwelling unit in 30 years if the AC is run for 14 Hrs in the summer months. Therefore Eq= Cooling load* 14* 30* 6.5 (Rs)

4. Calculation of RETV of a MIVAN-constructed room

Residential Envelope Heat Transmittance (RETV): RETV is the net heat gain rate (over the cooling period) through the building envelope of dwelling units (excluding roof) divided by the area of the building envelope (excluding roof) of dwelling units. Its unit is W/m2.

Uopaque	**U**nonopaque(W/(m 2 .K)	**WWR**	**SHGC Equivalent**	**Climatic Conditions**	**Coeff A**	**Coeff B**	**Coeff C**	**RETV value**
3.50948	5.8	0.2	0.8	Composite /Hot-Dry	6.11	1.9	70.94	19.51

$RETV = A * (1 - WWR) * Uopaque + B * WWR * Unon{-}opaque + C * WWR * SHGCequivalent$ (1) where,

$RETV$: residential envelope transmittance value (W/m2)

WWR: window-to-wall ratio; it is the ratio of the non-opaque building envelope components area to the envelope area (excluding roof) of dwelling units $Uopaque$: thermal transmittance of opaque building envelope components (wall, opaque panels in doors and windows, etc.)

(W/m2 .K) $Unon{-}opaque$: thermal transmittance of non-opaque building envelope components (transparent/ translucent panels of windows, doors, etc.) (W/m2 .K)

$SHGCequivalent$: equivalent solar heat gain coefficient; it is the fraction of incident solar radiation admitted through a non-opaque building envelope component including permanent external shading

1. The First step is to calculate the U-value of Opaque surfaces and non-opaque surfaces

Thickness (L in m)	**Conductivity (K in W/m.K)**	**R-wall (m2.K/W)**	**Air-film resistance (External, Rso in m2.K/W)**	**Air-film resistance (Internal, Rsi in m2.K/W)**	**Total -R (m2.K/W)**	**U-value** (W/m2.K)
0.2	1.74	0.11	0.04	0.13	0.28	3.50947963

A. To calculate the U-value of a wall, we need to determine the optimal thickness of dense concrete, which is 0.2 meters (the International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-8 Issue-5, January 2020). The conductivity value we will use is 1.74 W/m.k, (Annexure 1 of the Energy Conservation Building Code for Residential Buildings, Part I: Building Envelope Design).

B. Next, we can calculate the R-value of the wall by dividing its thickness by the material's conductivity, which gives us a value of 0.11 m2.K/W.

C. To calculate the total resistance, we must add the air-film resistance (external, Rso in m2.K/W), air-film resistance (internal, Rsi in m2.K/W), and the R-wall. This gives us a value of 0.28 m2.K/W.

D. Finally, we can determine the U-value by taking the inverse of the R-value, 3.5 W/m2.K.

2. The window-wall-ration is 20:100, i.e, 0.2.

3. The Solar-heat gain coefficients are as follows.

RETV is calculated using the formula (Equation 1), with coefficients given in Table 1, for different climate zones (for classification, refer to Annexure 6).

Table 1: Coefficients for RETV formula

Climate zone	A	B	C
Composite / Hot-Dry	6.11	1.90	70.94
Warm-humid	5.19	1.34	66.70
Temperate	5.27	0.95	78.92

5. Calculation of RETV of an insulated MIVAN-constructed room

1. The first step is to calculate the R-value of an Insulation product. This material is known as Fiberglass and has a 24 kg/m^3 density.

R-Glaswool	R-MIVAN	Air-film resistance (External, Rso in m2.K/W)	Air-film resistance (Internal, Rsi in m2.K/W)	Total-R
0.606	0.11	0.04	0.13	0.89

2. Using this value, we calculate the U-value of the Mivan wall and insulation.

Thickness	Total R-value	U value
0.22	0.89	1.12

3. The following shows the calculation of the RETV value of insulation and MIVAN constructed wall.

*U**opaque***	**U***nonopaque(W/(m2 .K)*	**WWR**	**SHGC Equivalent**	**Climatic Condition**	**Coeff A**	**Coeff B**	**Coeff C**	**RETV**
1.12	5.8	0.2	0.8	Composite/Hot-Dry	6.11	1.9	70.94	7.83

IV. RESULTS AND DISCUSSION

Eco Niwas sets a maximum RETV of 15W/m^2 in composite, and hot and dry environments. The Calculation shows that a dwelling unit constructed with the Aluminum formwork, concrete-based dwelling unit has a RETV of 19.51 W/m2, which makes it unsustainable. However, applying a 20mm thick insulation on the 64m^2 walls brings the RETV down to 7.83, thus, making it energy-efficient. The findings further show that applying 20mm thick insulation in a dwelling unit located in a place with climatic conditions similar to that of New Delhi saves 67.8% on the AC bill every summer season with a pay-back period of 19 years. Similarly applying 25mm thick insulation in a residential unit located in a place with climatic conditions similar to that of Jaipur saves 66% with a pay-back period of 22 years.

Thus, the findings prove that using insulation in residential units will promote sustainable development and is cost-effective, especially for the growing middle class of India.

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