MATHEMATICAL ANALYSIS OF TEMPERATURE PROFILES OF STANDARD ROOF CONSTRUCTION TECHNIQUES AND VACUUM INSULATION PANELS (VIP) UNDER LOCAL SUMMER CONDITIONS OF PAKISTAN

Umer Akram[1], Sajid Kamran[1], Khalid Iqbal[1]

[1,] Department of Mechanical Engineering, University of Engineering and Technology, Lahore, Pakistan. umer089@gmail.com

ABSTRACT: *Vacuum Insulation Panels have been considered the most efficient insulation available nowadays. However, the only factor because of which it is not used excessively is its high cost[1]. If by any means such insulation can be introduced in developing countries like Pakistan, the benefits will be obvious and contribution towards energy crises is evident. So this study has been aimed to analyze the thermal response of standard roof construction techniques (Village Slab, RCC) and comparison with VIP, and analyzing and interpreting all the temperature profiles obtained mathematically. Numerical methods have been used to simulate all the roof cross-sections and results have been obtained in graphical form. Having such mathematical formulation provides a flexibility for predicting thermal behavior over a wide range of conditions, hence can be greatly useful.*

Key words: Mathematical Analysis, Temperature Profiles, Vacuum Insulation Panels, VIP, Curve Fitting

1. INTRODUCTION

Vacuum Insulation Panel (VIP) consists of usually a porous core material that is covered by a vapour and air tight multilayer envelope as is shown in Fig. 1 [2], which serves to prevent any gas or moisture from the atmosphere that can otherwise adsorb in the core[3], and hence maintains thermal insulation properties over a wide range of time[4]. Its pore structure is open to evacuate all the gas in the panel. Getters and desiccants are added to the core which absorb the vapours and gases that can otherwise adsorb in the core material[5]. Opacifiers are added to make the core opaque to infrared and hence reduce the radiative conductivity of VIP[6].

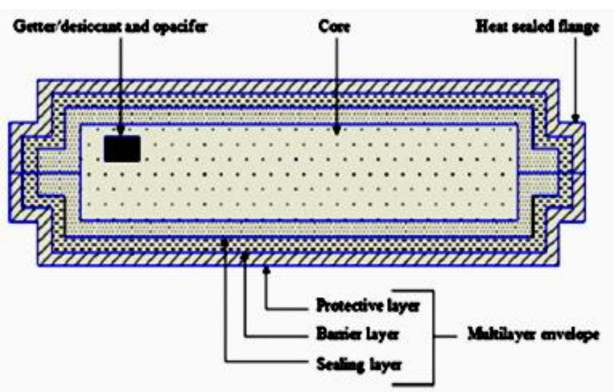

Figure 1 : Schematic of VIP

1.1 Roof cross-sections for buildings:

The cross-sections are the standards used in local areas of Pakistan. These have been simulated on ANSYS 14.0 and results were obtained in mathematical form. The details of cross-sections can be easily obtained from Punjab Works Department, Pakistan. As for VIP, it has been obtained by a review article on VIP[7], stated in references. The cross-sections analyzed are as follows:

1. Conventional Village Slab Roof X-section.
2. Conventional Reinforced Concrete Roof X-Section (RCC).
3. VIP Insulated Roof X-Section.

The temperature profiles of these cross-sections have been analyzed and discussed. Following boundary conditions have been used as provided by Pakistan Meteorological Department:

- Temperature at roof top = T_{out} = 43ºC.
- Heat Flux = Q = 750 KW/m^2.
- Ambient Temperature inside building = T_{in} = 28ºC
- Convection Coefficient = h_{in} = 5 W/m^{2}k^{-1} (for still air).

1.1.1 Conventional Village Slab X-section:

The conventional Village Slab X-section is mostly used as X-section in villages of Pakistan as well. The commonly used materials for such roof construction are Gobri Leaping (Cow Dung), Earth & wood(planks and garders). Details have been discussed in table 1. A plastic layer is usually introduced to prevent penetration of moisture through the roof. The temperature profile has been shown in Figure 2. The temperature has been dropped from 43°C to 33.4°C. The behavior has been shown by a blue line. In order to have a suitable mathematical relation for temperature drop in terms of depth of cross section, a third-degree polynomial is the most suitable choice after testing different curve fittings. So the approximate temperature at any depth ‘x’ can be estimated as:

$$T = -0.0067x^3 + 0.1808x^2 - 1.7071x + 42.999.$$

Table 1 : Layers of VIP X-Section

Layer No.	Material	Depth (cm)
1	Gobri Leaping	3.81
2	Earth Cover	11.43
3	Plastic Sheet	0.254
4	Wooden Plank	1.6002

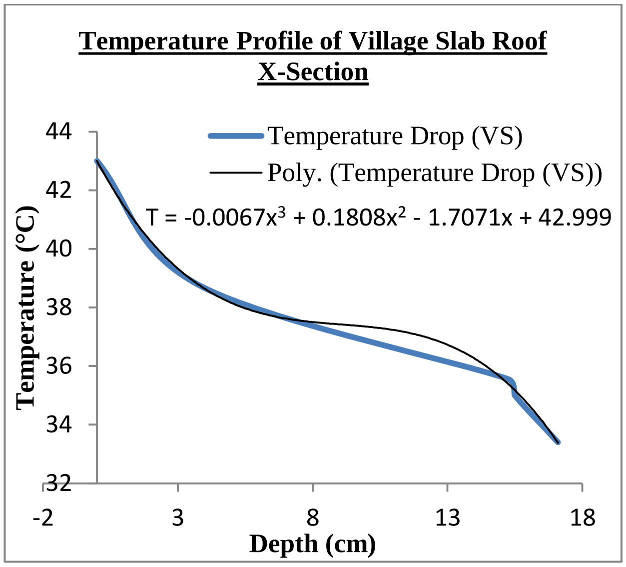

Figure 2 : Temperature Profile of Village Slab Roof X-Section

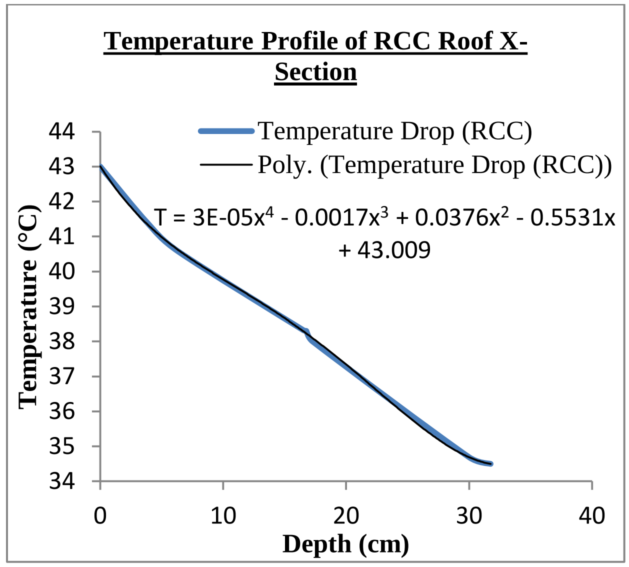

Figure 3 : Temperature Profile of RCC Roof X-section

1.1.2 Conventional RCC X-section:

The conventional Village Slab X-section is mostly used as X-section in cities or urban areas of Pakistan as well. The commonly available materials for such construction are Tiles (Bricks), Reinforced Concrete, Steel Bars, Cement etc. A plastic layer (usually Polythene sheet) is usually used to prevent penetration of water through the roof and to provide a little insulation effect. Details have been given in table 2. The temperature profile has been shown in Figure 3. The temperature has been dropped from 43°C to 34.49°C. The behavior has been shown in figure by a blue line. To have a mathematical relation for temperature drop in terms of depth of cross section, a linear equation or more accurately a fourth-degree polynomial is the most suitable choice after testing different curve fittings. Hence the approximate temperature 'T' at any depth 'x' can be calculated as:

$$T = 3E\text{-}05x^4 - 0.0017x^3 + 0.0376x^2 - 0.5531x + 43.009.$$

Table 2 : Layers of RCC Roof X-Section

Layer #	Material	Depth (cm)
1	Tile Layer (Brick)	3.81
2	Mud Plaster	2.54
3	Thick Earth	10.16
4	Polythene Sheet	0.254
5	Bitument Coating	0.508
6	RCC	12.7
7	Steel Bars	0.9525 (Dia)
8	Cement + Concrete Cover	1.905

1.1.3 VIP Insulation Roof X-Section:

The VIP (Vacuum Insulation Panels) has been recently introduced in developed countries. The core of VIP has thermal conductivity as low as 0.004 W/m.k [7], making it one of the best solutions of insulation nowadays. A Barrier layer (usually Polythene sheet) prevents permeation of moisture through the panel, which can otherwise affect the conductivity value of core. Also protective layers are used on either side of the panel so as to prevent the core structure from any possible physical damage[8].

As far as the thermal behavior is concerned, the case of VIP is a bit complex. This is due to a sudden decrease in the temperature across the core of VIP, making it difficult to have any suitable curve fit for the entire temperature profile. Hence, for the sake of simplicity, it has been divided in three regions and each has been dealt separately. The cross section details and these regions are discussed as follows in Table 3 and Figure 3.

Table 3 : Layers of VIP X-Section

Layer #	Material	Depth (cm)
1	Concrete Plate	2
2	Crushed Gravel	3
3	Fleece	0.2
4	Barrier Layer	0.7
5	Protective Layer	0.8
6	VIP	2
7	Protective layer	0.5
8	Barrier Layer	0.3
9	Concrete	18
10	Interior Plaster	0.5

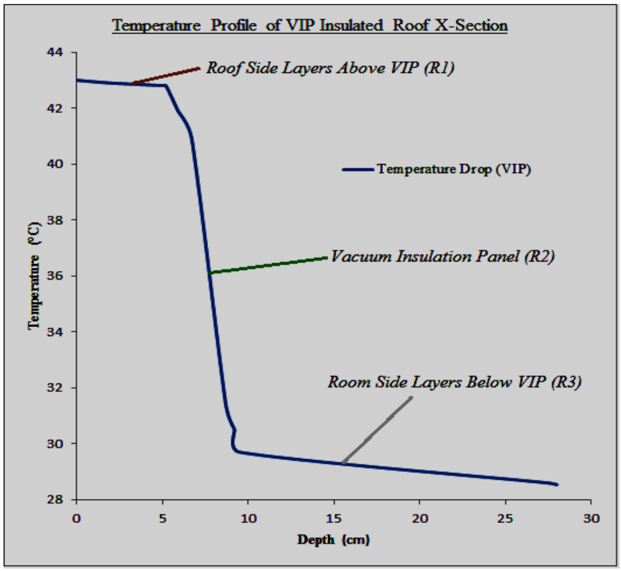

Figure 4 : Regions of VIP X-Section Temperature Profile

1.1.3.1 Region 1 – Roof Side Layers Above VIP:

The roof side consists of layers of concrete, crushed gravel and fleece. These layers are useful as far as the structural reliability of cross section is concerned. The solar flux is directly incident on this region, hence it is the hottest region in roof x-section. Thermal behavior of this region is almost linear, but can still be better predicted if a quadratic fit is used instead for temperature profile as shown in Figure 4. So the temperature 'T' at any depth 'x' can be calculated as:

$$T_{R1} = 0.0037x^2 - 0.057x + 43.$$

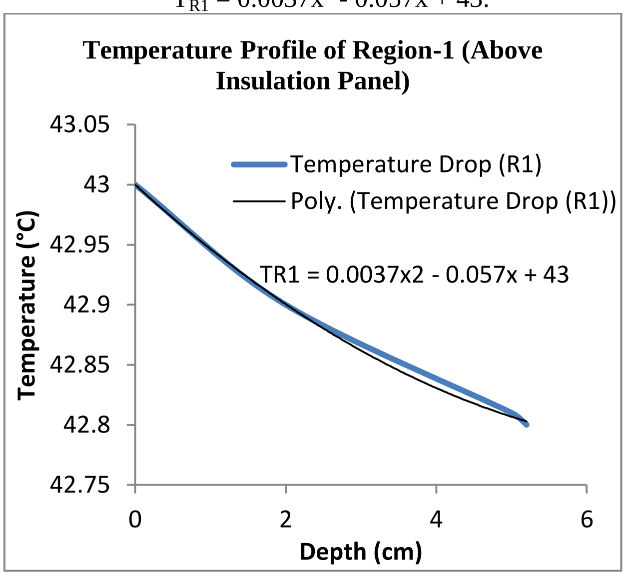

Figure 5 : Temperature Profile of Region-1

1.1.3.2 Region 2 – Vacuum Insulation Panel:

The VIP consists of barrier layers, protective layers and evacuated core. This is the insulation that is sandwiched within roof layers. The evacuated core is usually fumed silica whose thermal conductivity is considerably low and provides a good quality insulation. It blocks almost all the heat flow towards the interior and only a fraction of heat is passed along it. The thermal behavior of this region can be best predicted by a third-degree polynomial which is the most suitable fit as shown in Figure 5. So the temperature 'T' at any depth 'x' can be calculated as:

$$T_{R2} = 0.5877x^3 - 13.71x^2 + 101.36x - 199.55.$$

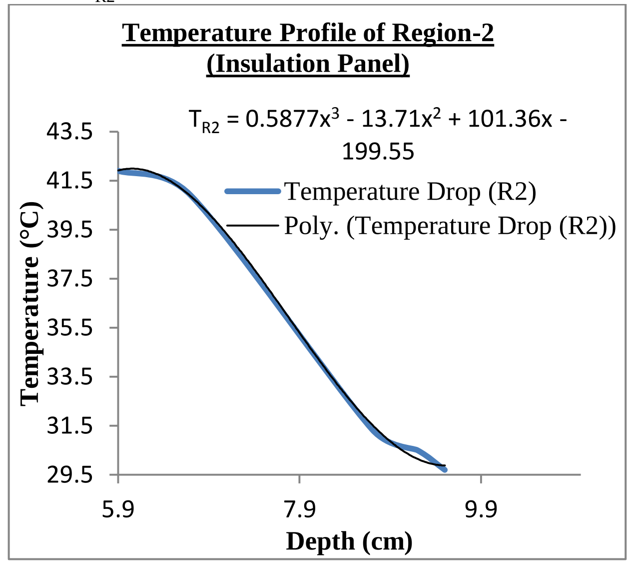

Figure 6 : Temperature Profile of Region-2

1.1.3.3 Region 3 – Room Side Layers Below VIP:

The room side layers are concrete plate and interior cement plaster. These layers provide physical protection and smooth surface at the interior side. The cement plaster is a thin layer of cement-sand mixture applied inside the room for better finishing. Thermal behavior is this region is the most simple case and a simple linear equation can easily describe the behaviour as shown in Figure 6. Hence the temperature 'T' at any depth 'x' can be simply calculated for this region as:

$$T_b = -0.062x + 30.289.$$

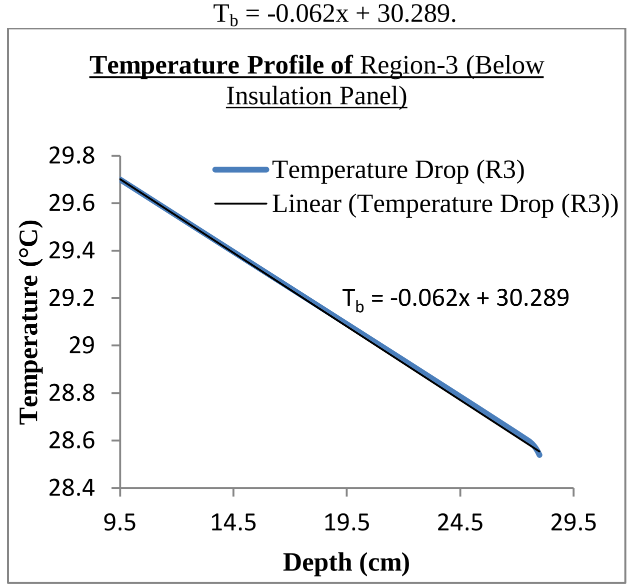

Figure 7 : Temperature Profile of Region-3

2. CONCLUSIONS:

The aim of this study was to describe the temperature profiles of different roof standards in terms of mathematical relations. Care has been taken in the previous work wheen thermal simulations and temperature profiles were obtained. Validation work for thermal simulations has been described in one of the previous articles. These mathematical relations provides a systematic set of solutions that can very well describe the behavior of according cross sections at any given depth. Small variations could still be there, but overall estimation can be extremely helpful and beneficial.

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