Theoretical Model of Heat Flow in the Roof of the Maramures (MM) Tiny House

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Abstract: *This paper is a thermal performance research of the roof in MM tiny house. The entire research is currently on going and providing a model of heat transfer via convection and conduction for passive and NZEB house design. The contribution of the research is to provide a deeper understand of the heat flow and the heat loss thru different shapes and how these can provide a new aspect in design of houses under tighter requirements for energy performance in the context of global warming.*

Keywords: *MM tiny house, roof, pitch, thermal performance, heat, speed, NZEB*

1 INTRODUCTION

Roof design in mainstream, is the outcome of two groups of considerations: Architectural and structural. Architectural defines the shape, functionally, size of building and other considerations regarding visual aspects. Structural design accounts for loads, deflection span and code requirements. In single family house design (as oppose to commercial buildings) the minimum roof pitch is defined in the building code and the standards of the design at hand. Looking at historic examples of roof design in extreme climate conditions (the Maramures – MM tiny house in North Romania and Turf roofs in Scandinavia), shows extremely high roof pitch. A pitch that is exceeding the need to prevent accumulation of snow. This interesting fact, raises a few questions: If the roof pitch is higher than the sole need to prevent accumulation of snow, can the shape of a roof have an impact over the thermal performance of the house? And if so, what is the impact of different roof shapes on the thermal performance? This this paper is proposing the roof pitch as a factor in the consideration of the thermal performance of the house.

Fig.1. A tiny MM house

In a fairly recent literature review Al Obeidi et al. (2014) [7] writes about passive cooling techniques, discuses through reflective and radiative roofs in tropical environments, using different materials and different coloring systems as a reflective solution for radiation and reducing heat buildup inside the roof. His findings indicate that roof design is relevant to Energy management, and, that effective roof design has major impact over climate change in heavily populated areas, however he does not provide a specific about how the roof shape effects the energy flow and the heat capacity.

Fig.2. A Turf house - Iceland [5]

In 2008, in an article published by the English heritage institute, named Energy conservation in traditional building [3]. The author speaks about the increasing Carbone dioxide footprint of houses following the global climate change as average temperatures increase. The government of the UK is wishing to reduce the country's dependence of fossil fuel use and to reduce emissions by 60% before 2050. The article is providing the argument that one can rehab his house in order to reduce the heat loss through the building envelope floor and roof. The test cases which the article speaks of, are traditional houses built earlier then 1919. In The very second page of the article in a highlighted paragraph, it is emphasized that prior to looking for alternate energy sources it is imperative to look for measures to conserve it. The proposed Roof solution is to insulate the floor of the attic from the livable space underneath. However, the article doesn't mention what is the effect of the roof pitch over the way heat flows thru the roof cavity, furthermore, the question how this effects volumetric heat capacity at the basin of the roof -remains unanswered. In another article issued in 2014 named "*Combined use of design offer experiment and dynamic building simulation in* *assessment of Energy efficiency in tropical residential buildings*" by Aidin Nohabar [1] is analyzing a case study, of two buildings with pitched roof and covered clay tiles. Mr. Nohabar identifies different elements in the building causing, different cooling loads. In both buildings of the case study, the roof is peaking with the highest cooling loads of (215.32 KWh/m^2). The ceiling suspended under the roof is identified as the maximum cooling load and the lowest level of Energy saving. His conclusion is that ceilings and the material of which it is made of, has the greatest effect on energy usage and savings.

William Chung, in his article in 2006, [9] writes in the introduction: "*by changing design parameters such as shape, orientation, and envelope configuration, a high-quality designed building can consume 40% less energy than a low-quality designed one*". He proposes two methods for shape analysis. One - the part-whole approach of which determines the building shape from its spatial elements. This part-whole approach is capable of defining a wide range of shapes. The whole-part approach defines a building shape by its external boundaries and represents its internal spatial elements implicitly. Because the whole-part approach can easily describe as the building geometry for energy simulation programs, it is adopted in several optimization studies on energy performance. A few studies assumed a rectangular building plan and optimized by its geometry via aspect ratio. The other method, an energy performance based as an output of design software. This geometrical shape is selected because most energy simulation programs used to estimate building energy consumption by modeling exterior walls as line segments. The polygon provides a basis to consider a more complicated building shape, since a curve can be approximated with line segments. It is also reasonable to limit the scope to simple polygons since buildings do not have boundaries that intersect.

Most energy modeling software are considering walls as lines and accounting for different factors: physical – properties of materials of the wall such as density, thermal resistance, continuity, thermal coupling Environmental considerations - such as difference of temperature, physical location, and orientation Geometry factors - such as length, thickness, openings (fenestration), height.

The shapes of the building are assumed in the geometry properties. Meaning, a wall or a hip of a roof will be represented by the diagonal line versus a vertical line. However, the software does not account for the direction of its natural convection effected by the shape itself. More so, it does not consider the volumetric heat capacity captured by the shape. hence, modeling software, does not account for the depth of the energy required to account for behind the wall (all is assumed by length and height). Meaning the depth of the cavity and how the energy is flowing and accumulated.

For example, it is logic to assume that a sphere ball made of the same material and that would have same surface, volume, and in the same environment will treat energy in a completely different matter than a spiral shape with the identical properties. It is intuitive to understand that heat will be stored inside the spiral and different areas whereas in the ball sphere very evenly, and that the emery (heat loss) will be different comparing the two shapes and uneven within the spiral.

It is clearly demonstrated that software algorithm can take into account different considerations such as material costs, densities, thermal properties of materials and others. When adding long term maintenance cost to the algorithm of the program and combining all together with conventional considerations, the result is a model that is accounting for a more efficient shape in conjunction with its surroundings.

From Heat transfer book "shapes and forms …." Behrooz M. Ziapour et al (2012) [2] writes in his article: "*Natural convection in enclosures is a kind of classical problem in heat transfer. The shape of the wall, flow and heat transfer inside enclosures have numerous engineering applications such as heat exchangers, energy-storage devices, solar collectors, greenhouses, double-wall insulation, electric machinery, cooling system of electronic devices, natural circulation in the atmosphere, etc.*" he proposes a model explaining the entropy created and the flow of convection in green houses with two different roof types - arched roof and one-sided roof.

2 THE THEORETICAL MODEL OF THE HEAT FLOW IN DIFFERENT ROOFS

2.1. Proposal of experiment and hypothesis

For the purpose of developing a theoretical model of the heat flow in different roof types, the following figure and table is proposed. This is a representation of three models of the research: the first (a), is a typical single-family house with a roof pitch as required by the International Building Code requirements (IBS) of 2015 [6]. The second is a typical turf roof design from Scandinavian countries. The third is the typical MM tiny house with the highest roof pitch.

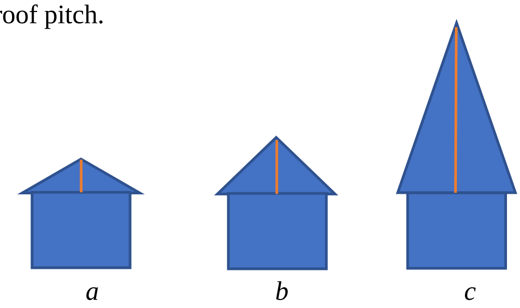

Fig.3. Three models of roof of experiment

Table.1. Summary of roof slopes

Type	*a*	*b*	*c*
Roof pitch	IBC 2015	Turf house	MM tiny house
Pitch % slope	50%	100%	135%
$h/\left(\frac{l}{2}\right)$	1:2	1:1	1.5:1

Whereas (h) is the height of the roof (marked red) and the width of the base is marked l). Hypothesis: The speed of heat flow along the height of the hip, is affected by the angle at the base of the roof (whereas the length of the hip is measured by the angle and the height of the roof).

2.2. Design of experiment

For the purpose of this paper, in the frame of experiment the intention is to create a connection between the dimensions of the roof and the variation of temperature. The measured impact of the heat flow is represented by the speed of which the heat is flowing through out the roof cavity, specifically alongside the hip.

In order to assure effective measurements, the experiment will apply OFAT method (One Factor at A Time, specifically- speed in minutes [Min]) while all other factors are controlled by remain constant throughout the entire duration of the experiment, for all models tested. The following table describes the different factors of the experiment and their types.

Table.2. Factors of experiment

Factor	Controllable	Type
Angle of hip at base	Yes	Design factor
Time measurement	No	Design factor
Speed of heat flow	No	Design factor
Initial Temp	Yes	Design factor
Air movement	No	Noise factor

Application of OFAT method means that during the experiment only one factor is measured every time separately - the different angle at the base of the roof. Consequently, the result will quantify the sole effect of angle over the speed of which the heat spreads alongside the hip. All three models are made by one material type - OSB 12mm thick from one random sheet. All three models are made with identical base length of 700mm. All models are measured with one set of calibrated and certified thermometer and probe. The experiment will take place in a controlled environment where temperature, air flow and atmospheric pressure is equal for all models.

2.3 Description of experiment

The experiment will compare the speed of the heat flowing thru the roof cavity in three different roof types: a- modern roof with a pitch of 50% (22^o angle at the base per the minimum requirements of the International Building Codes 2015. b- Scandinavian historical Turf roof with a pitch of 100% (45^o angle at the base) c- the typical MM tiny house with high roof pitch (135% 58^o-62^o degrees angle at the base).

All tree roofs are presented below. Roof type (*a*) with a base angle of α=22^o; Roof type (*b*) with a base angle of α=45^o; Roof type (*c*) with a base angle of α=61^o.

At the top of the hip, a heat source is applied, and a thermometer probe is measuring the temperature at the base. Once the heater is turned on and the heat is flowing down alongside the hip, a timer is activated and will continue measuring until the heat reaches the base. Once the temperature at the base has increased by ($+\Delta t 3$°C) from the ambient temperature, the timer is stopped, and the time measurement is recorded. The process is then repeated fifteen times for every roof model (in total 45 measurements). The length of the hip is known (by the angle and the length of the base). Then the speed of the heat flow is obtained as a result of result of the length divided by the time: $\Delta T = \mathrm{T2} - \mathrm{T1}$; $\Delta \mathrm{t} = +3$°C and $V[\frac{m}{s}] = \frac{l}{\Delta T}$. The result will provide the speed of the heat flow for all three different roof models.

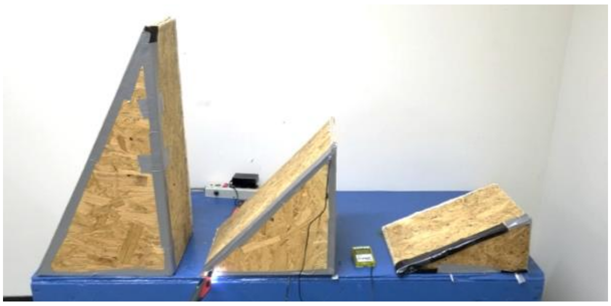

Fig.4. models of roof types with same base length

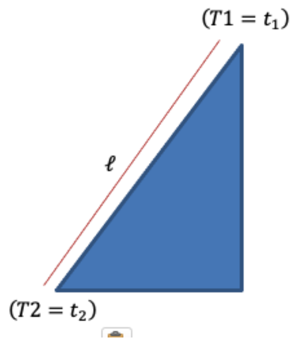

Figure 5. Average speed of heat flow inside the roof

3 ANALYSIS OF RESULTS

Once the experiment is concluded and all fourth five results are recorded then, a process of statistical analysis may begin. At first, a distribution test will define weather the results have a standard distribution model or of a different type. If the results will fall with the criteria of standard distribution, then a validation test for small field of results may be applied. For example- Grubs test. In the event that the results are random and not within the criteria of standard distribution then, such test cannot be applied. Consequently, every measurement of which is exceeds the average results of the other measurements by 20% or more will be disqualified and redone. Then, the average value of all fifteen measurements will define the average speed of which the heat flows alongside the hip. The results will be presented in a graphical manner per standards of OFAT design next to a table, presenting the measurements and the average speed [cm/min] for every roof model.

4 CONCLUSIONS AND CONTRIBUTIONS

The shape and orientation of bodies is long known to have effect of the direction of convection and heat flow. ″While heat exchange by thermal radiation does not depend on a transport medium, the geometric configuration of bodies exchanging heat by this mechanism is quite important. The amount of the radiation emitted by one body that is intersected by another is highly dependent on the size, shape, and relative orientation of the bodies″ [4] Although, there is a clear references to the problem and a clear indication to the existence of the phenomena in articles as well as classic literacy of heat transfer and thermodynamics, the current stage of research, to the best of my knowledge and to the best of my research does not provide clear model that predicts and quantifies the phenomena of heat flow in the roof cavity. Hopefully, the results of the three roof models experiment, will validate the hypothesis and will provide results showing, that roof shape and its orientation and angle of hip, has an impact over the speed of which heat flows in the roof cavity.

The importance of understanding the phenomena and the theoretical model will provide a meaningful and important tool in multiple aspects: First - understanding the phenomena and having the ability to predict and quantify it - has importance of itself in the field of thermodynamics and convection. The model will be made applicable in multiple fields of applied engineering and physics. Second, the result will provide a new design criterion, for roof design beyond the current existing ones (architectural and structural engineering). Understanding the heat flow in the roof cavity and its impact over the energy consumption of the house will reduce initial construction costs, long term utility costs and maintenance, while having a positive effect on the environment.

5 DISCUSSION

In the modern scientific world, scientific knowledge is developed layers upon layers where every layer is based on the knowledge of the previous ones. The findings of a more energy efficient roof design from previous generations will prove that some gained knowledge of ancient generations was forgotten and now re found and vitalized. Once more. To date, in the age of global warming, new technologies and solutions for energy efficiency are sought out. The higher pitch roof is expected to deflect the heat towards the livable space of the house faster and more efficient, consequently decreasing the heat consumption required. More so, the high pitch roof has an increased roof surface, that during wintertime absorbs sun light and accumulates greater amount of heat. In the summer the heat is absorbed in the roof cavity during the daytime and in the evening, while temperature drops, the heat is deflected heat towards the livable space below creating a more pleasant atmosphere. Meaning, the high pitch roof creates a benefit of reducing energy consumption during summer and winter.

The high pitch roof design contributes into the reduction of energy consumption of the house in the following ways: first - reduces the size of mechanical equipment (air condition and heat pump). Second - harnessing the sun light to generate heat reduces long term utility bills and additional cost of maintenance. Third - the effect on the environment is positive as well. A smaller carbon footprint and lessor use of fossil fuel materials. Finally, the new roof will help create a better performing house (passive or NZEB) in a more friendly environment.

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