Experimental Results of Heat Flow in the Roof of the Maramures (MM) Tiny House

Adi Ben-Senior[1]*, Nicolae Ungureanu[2], Mihai Banica[3]

Abstract: *This paper is presenting the results of the experiment of the heat flow via convection in the roof of the MM tiny house and additional two other reference models. The convection in the roof cavity is highly affected by the angle at the base of the roof. The model and its experimental results provide predicative and quantifiable result of the efficiency performance of the convection in the roof cavity. The method can be used as a new tool for designing a hip roof when one wants to account for thermal performance in addition to architectural and structural considerations. The tool provides a more sustainable design and a real application for passive and NZEB house design.*

Keywords: *MM tiny house, roof, pitch, convection, heat, speed, time*

1 INTRODUCTION

The heat flow via convection in the roof of the MM tiny house is a significant issue for the modern Passive house and NZEB design In the previous published article [1], mentioned the considerations roof design in mainstream, as 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 [3]. 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. Following the historic MM tiny house in North Romania and Turf roofs in Scandinavia, the theoretical proposed the high pitch of the roof as a factor contributing to the thermal performance of the livable space. The experiment answers the two questions rose previously: a- Does the roof pitch has thermal performance over the livable space? b - And if so, what is the impact of different roof angles on the speed of convection alongside the hip in the roof cavity?

This this paper is providing the description of the experiment, the considerations while experimenting, the equipment used for conducting the experiment. Finally, the paper will provide the experiments results and discussion of the impact of the pitch on the thermal performance of design NZEB and passive houses.

Fig.1. A tiny MM houses

During 2019 the experiment was designed and conducted in Radford Virginia USA. Background: measuring the speed of convection and the heat speed as it develops alongside the hip of a roof cavity model is a fairly delicate process, and for that reason in other examples mentioned in the previous article, used theoretical model such as numeric analysis, finite element and others. However, there is great importance for true field measurements and empirical results. The first attempt of conducting the experiment was on a smoke source introduced at the top of the hip and a video camera recording the time of which the smoke reached the base. The attempt failed. While cold smoke might have represented the convection properly, the introduction of the smoke without the ability to extract identical amount of air from the model increased the internal pressure and caused the model to become pressurized providing false results.

The second attempt of conducting the experiment, hot smoke was introduced to the model of the roof cavity. However, the speed of heat proved greatly different from the speed of the smoke videoed. The third attempt measured the time of which the heat at the base of the hip increased by ($+\Delta t 3°C$) from the ambient temperature as of the time the heat sourced was introduced at the bottom of the hip roof.

Fig.2. Introduction of smoke into the roof cavity

2 PRE-EXPERIMENT

Ambient conditions pre-experiment and the chamber of experiment: Since the results are highly affected by atmospheric conditions the experiment took place in a completely internal closed room inside a building, without access to exterior walls or roof. the room had a seal around the door and without windows. The temperature inside the building was present and kept constant four hours prior to the experiment and while the experiment was conducted. All air vents and air condition ducts were sealed off in order to achieve as much as possible constant and identical conditions prior and throughout the entire experiment. Inside the experiment chamber a standard non-scientific non calibrated barometer thermometer and hygrometer to assist monitor ambient conditions.

Table.1. Factors of experiment

Factor	**Controllable**	**Factor Type**
Angle of roof	Yes	Design
Time measurement	Yes	Design
Speed of heat flow	Yes	Design
Environment of test	Yes	Constant
Material of roof	Yes	Constant
Heater for the roof	Yes	Constant
Ambience temperature	Yes	Noise
Temp. reading equipment	Yes	Constant
Ambient temperature fluctuation	Yes	Noise

Predesign of *experiment*: to achieve consistent and meaningful results Randomization, replication and blocking of undesigned factors were applied as can be seen in the following figure:

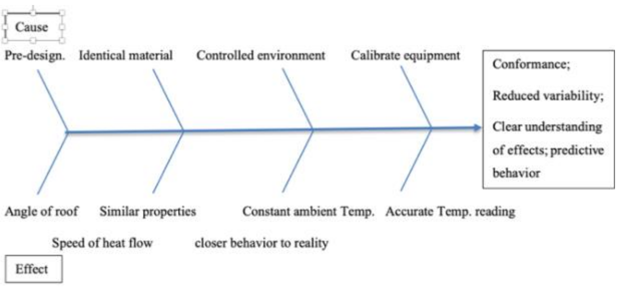

Fig.3. Cause effect diagram of experiment factors

Scaled models: all three roof models were scaled identical to have a base length of 700mm. and made one side of the roof. At the base roof. All models were wade of a random sheet of OSB 5/8” [inch] thick. All models are made the same depth 12” [inch]. All models were placed on one wooden flat table surface not touching any wall of the chamber. The lights used are standard indirect not heating cold T5 bulbs integrated in the dropped ceiling of the test chamber. All models are sealed with a sealing gum from one random tube and all models were sealed all round connections with a standard Gorilla tape randomly chosen.

The introduction points of the heat source are identical in all models 1” one [inch] from bottom. The introduction point for temperature measuring probe is for all models, one 1” [inch] from the top. In order to block noise effect of all three models were added an interior parallel surface 1” one [inch] off set from the hip made of Expanded Polystyrene at the entire width of the model top to bottom and then covered with the front face of the roof with identical OSB sheet 5/8” [inch] (as shown in figure one above). The purpose of the Expanded Poly Styrene surface is to provide a flat surface with the least amount of possible air turbulences and to eliminate as much as possible all noise factors and other factors that may affect the ability to measure only the heat flow. That part completes the chamber of experiment, surrounding and models and scaled models of roof.

Table.2. Angle of experiment

Type	*a*	*b*	*c*
Roof pitch	IBC 2015	Turf house	MM tiny house
Pitch % slope	50%	100%	135%
Angle experimented	22^0	45^0	61^0

3 MAIN EQUIPMENT OF EXPERIMENT

Equipment of experiment: all raw data record kept in its original format Excel and Apple MacBook laptop was used is the main processing platform. The heat source used for the experiment is a couple of identical random chosen, smothering irons by Weller, with 60 watts capacity each. Since such piece cannot be calibrated and certified in a scientific measure - all measurements for all models for the entire duration of the experiment - used the same heat source. In such fashion, any inaccuracy or defect will be applied identical to all models and will not affect one model over the other one way or another. Both smothering irons were introduced on both sides of each model to provide equal heat distribution throughout the entire section’s depth 12” [inch].

To prevent any heat loss at the introduction cavity a copper sleeve was applied over the arm of the smothering iron to fill the gap around the hole in all roof models. As a timer and a dual thermometer probe a Cryopak iMINI newly calibrated and certified was used. The Cryopak arrives calibrated and certified from the manufacture and used mainly in the field of medicine and food transport which makes it a good fit to measure small temperature changes. (temperature accuracy of $0.5\,^0$C and resolution of 0.1^0C) The main unit is the operation platform that includes a thermometer and a timer. The probe with the extended chord was used to measure inside the temperature inside the roof cavity. The measurements recorded were stored inside the internal memory and then downloaded to the laptop as two files: .CVS which was kept as the raw recorded data and .XLS format which was used to edit and process the data.

Fig.4. Weller Soldering Irons used as a heat source

Fig.5. Thermometer dual probe and timer unit

4 EXPERIMENT AND RESULTS

At the bottom of the hip a heat source was introduced, and a stopwatch measured the time in minutes and seconds until the temperature at the base of the hip was higher than the ambient temperature by (+Δt3℃). Then the data was downloaded to the laptop and the following measurement was then conducted in the next model and in the same fashion in the third model.

By the time all three measurement of all three models were taken, the first model has cooled down to the ambient temperature of the chamber and was ready for the next measurement. The process repeated eight times. Then a normal distribution test was conducted for each model. Since the measurements did not fit in the criteria of normal distribution test the test was extended to twelve and finally to fifteen measurements of each model. The measurements of all models were still random it was decided to keep the experiment at fifteen measurements for every model.

Fig.6. while performing the experiment

Table.3. Measurements of each models

RUN	**Type a** time [min]	**Type b** time [min]	**Type c** time [min]
R1	0:12:40	0:12:50	0:12:30
R2	0:10:35	0:04:45	0:15:25
R3	0:13:25	0:07:45	0:12:25
R4	0:14:20	0:21:45	0:16:00
R5	0:24:20	0:06:15	0:25:10
R6	0:16:10	0:04:40	0:21:15
R7	0:18:10	0:05:55	0:25:25
R8	0:16:05	0:05:45	0:11:40
R9	0:09:55	0:08:40	0:14:40
R10	0:08:35	0:22:00	0:14:00
R11	0:11:55	0:05:40	0:30:40
R12	0:11:20	0:03:25	0:26:50
R13	0:12:45	0:02:40	0:24:35
R14	0:13:25	0:08:10	0:27:30
R15	0:12:40	0:08:35	0:12:25

Then the speed of the heat flow is obtained as a result of the length divided by the time: $\Delta T = \mathrm{T2} - \mathrm{T1}$; $\Delta t = +3℃$ $V[\frac{m}{s}] = \frac{l}{\Delta T}$

The results of the average speed of heat flow alongside the hip roof is presented in the following table.

Table.4. Summary of measurements

Type	***a***	***b***	***c***
Angle experimented	22^0	45^0	61^0
Average time [cm/min]	2.72	5.86	3.76
Performance index	100%	215%	138%

4 CONCLUSIONS

The experiment indicates the Hypothesis of the experiment - is valid (Hypothesis: The speed of heat flow along the height of the hip, is affected by the angle at the base of the roof). Higher angles proved faster convection. The turf roof model (b) showed the fastest convection at a rate of 5.86 cm per minute. The next is the MM tiny house roof model (c) at 3.76 cm per minute and the modern roof design model (a) at 2.72 cm per minute. The following figure explains the time performance as a result of the different pitch

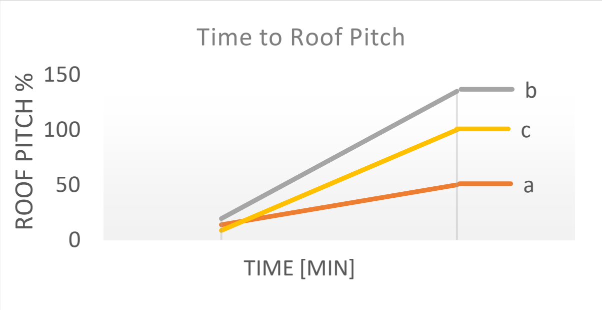

Figure 7. performance index of time against pitch for the three roof models

Two of three models, with a higher roof pitch proved to deflect the heat in the roof cavity faster to the livable space, than the modern roof design. hence, it is safe to assume that A higher roof pitch is a better suited for winter climate by generating usable heat in a passive fashion using its geometry. The turf roof model outperformed the modern roof by 115% and the MM tiny house by 77%. Considering that Scandinavian winters are even colder than in Northern Romania goes along with the results of the experiment.

5. DISCUSSION AND CONTRIBUTION

5.1 Proposed improvement for the roof energetical contribution

The experiment measured the sole effect of the angle at the base of the roof. However, there are multiple factors that may prove the MM tiny house to be even more effective than the turf roof. Some of such factors are **a**-the color of the roof. While the turf roof is covered with the vegetation the MM tiny house is made of dark brown shingles which is increasing the amount of heat captured inside the roof cavity by the sun's radiation [4]. **b**-total roof surface - the Turf roof is a simple one side hip roof however the MM tiny roof is of two-sided hip creating compound angle, consequently adding addition captured heat to the convection [5]. **c**-increased roof surface - the bigger the roof the more heat is captured inside the roof cavity. Since the MM tiny house has a higher pitch and two-sided hip, the total surface of the roof is bigger than the Turf roof. It is proposed to conduct an experiment measuring the total effect of all factors together to measure the amount and speed of heat transferred to the livable space.

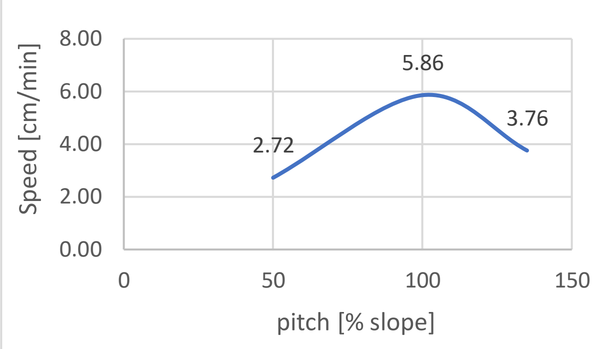

Figure 8. speed of convection in the three roof models

5.2 A method of application for energy savings in passive and NZEB house

Passive and NZEB house design and are applying methods of harnessing natural green resources of energy to climate control of modern housing. Some of these methods, were applied centuries ago as a solution for lack of modern technology. The results of the experiment provide an effective method to reduce energy consumption and long-term utility bills by up to 20% of a household by changing the geometry of the roof, in accordance with its surrounding climate. A climate map can be associated with the fig 8 above and together can help define she shape of the roof and the angle at the base of its hip in order harness the added heat to the house.

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″ [2] The historical MM tiny house proves to apply passive house design methods that, once understood and analyzed by the experiment to modern NZEB and passive house 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.

REFERENCES

[1] Adi Ben-Senior, (2019), *Theoretical Model of Heat Flow in the Roof of the Maramures Tiny House*, Scientific Bulletin, Serie C, Fascicle: Mechanics, Tribology, Machine Manufacturing Technology, ISSN 1224-3264, Vol. 2019 No.XXXIII

[2] Alan J Chapman, (1987), *Fundamentals of Heat Transfer*, ISBN 0-02-321600-x, pp.15

[3] IBC (International building codes), (2015), https://codes.iccsafe.org/content/IBC2015 accessed on Feb 2019, from http://www.alfa_beta.com

[4] Karam M. Al-Obaidin, Mazran Ismail, Abdul Malek Abdul Rahman, (2014), *Passive cooling techniques through reflective and radiative roofs in tropical houses in Southeast Asia*, A literature review, *ScienceDirect,* Vol.03, pp.283-297 https://doi.org/10.1016/j.foar.2014.06.002

[5] Salam Hadi Hussain, Ahmed Kadhim Hussein, Mahmoud Moustafa Mahdi, (2011), *Natural convection in a square inclined enclosure with vee-corrugated sidewalls subjected to constant flux heating from below Nonlinear Analysis*, Modelling and Control, Vol.16, No.2, pp.152-169

Authors addresses

[1]Adi Ben-Senior, Eng. PhD student, Technical University of Cluj-Napoca, Faculty of Engineering, Baia Mare, 62A Victor Babes St.;
e-mail: abensenior75@gmail.com
[2]Nicolae Ungureanu, Professor, Technical University of Cluj-Napoca, Faculty of Engineering, Baia Mare, 62A Victor Babes St.,
e-mail: Nicolae.Ungureanu@cunbm.utcluj.ro
[3]Mihai Banica, Assoc. Professor, Technical University of Cluj-Napoca, Faculty of Engineering, Victor Babes St., no.62A,
e-mail: Mihai.Banica@cunbm.utcluj.ro

Contact person

[*]Adi Ben-Senior, Eng. PhD student, Technical University of Cluj-Napoca, Faculty of Engineering, Baia Mare, Victor Babes St., no.62A, +40-735-903903,
e-mail: abensenior75@gmail.com