A Thermal Study of Roof Shapes and Materials in Hot Dry Climates: Insights from a Simulation from Rajasthan, India

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Abstract

Across the globe, in hot and dry climates, heat gain through the envelopes of the buildings has been a major issue. Since hot and dry climatic regions generally have low rise structures, major heat gain is always through the roofs. Therefore, conventionally, roof shapes have been created to respond to the local climate and context to control heat gain. However, the limitations of construction technologies and skilled labor together with the other factors have made it difficult to construct different roof types in almost all the regions. Similar conditions make it difficult even for materials to be experimented with.

In this context, this paper examines various types of roof shapes and materials usually found in vernacular habitats in hot and dry climate regions, although they may or may not be concurrently available. In this research, these roofs have been installed on a standard model and simulated for a complete year cycle considering the weather data. The cases examined were in Jaisalmer, Rajasthan. The research employed TRNSYS as a software for the simulation, as it is a reliable tool for energy transfer, and human comfort measurement. The outcomes have been converted into percentages of comfort conditions achieved for each roof type.

This paper concludes that higher the percent of result, higher will be the human comfort condition. It is thus concluded that gable roofs combined with ceramic tiles produce the maximum thermal comfort conditions indoors in this climatic region. The best performing shapes are Gable, Segmental and Hip in the same order. Thatch was the best performing material.

Keywords: Roof Shapes, Roof Materials, Hot and Dry Climate, TRNSYS.

Introduction

In any given built environment, thermal comfort is one of the primary needs of a user. In fact, to occupy and use the space, either active or passive means of achieving thermal comfort is needed. However, often, active means of achieving thermal comfort are energy intensive and may cause economic as well as environmental impact. Therefore, the best way to achieve thermal comfort is through passive means, which aren't energy intensive and utilize no operational energy though any component of embodied energy like active means.

Heat gain in a building either from an internal or an external source. Internal heat gain happens often through either machine, people or building surfaces which are subjective and may change or shift over duration. On the other hand, external heat gain is often through direct or indirect solar sources or convection currents. A building comprises of primarily the envelope and structure and solar radiation through its envelope plays a major part among the components of heat gain in any built form. A building envelope comprises of roofs, walls, and fenestrations; roofs being the first receiver of sunlight and its heat. The structure generally does not contribute to the heat gain. In fact, the envelope is the major contributor to the heat gain especially through solar heat.

Traditionally, roofs have been very simple in structures and technologies. They use shapes like domed, flat, pyramidical, etc. combined with materials like RCC, timber, metal, etc. They also use techniques like cool roofs, roof sprays, gunny bags, etc. often on flat roofs. However, differently shaped roofs usually cannot adapt these techniques. Similarly, even materials could be limited to types of shapes due to their structural complexity.

Mostly, non – traditional materials are used for flat roofs. Therefore, flat roofs are used mostly for heat control where there is a need for the reduction of heat gain. Although, other shapes are combined with materials and utilized for similar purposes, they are often not used due to their complexity of structures. Techniques have also been combined mainly only with flat roofs owing to their applications.

Combining roofs with materials has its limitations. In fact, only a few materials can be experimented with such techniques, although sometimes, there might be better options available.

In this context, this study examines the possibilities of combining various shapes and materials to work together to create an optimum roof solution which is feasible for achieving thermal comfort in hot dry climates. Its aim is to study various types of roof structures and insulations applicable to reduce indoor temperature. Its objectives are:

- To study the various types of roof shapes, and materials and their effect on indoor air temperature. (SDG 9, SDG 11, SDG 12)
- To apply the roof shapes and materials in various permutations and combinations to create integral models for simulation. (SDG 11, SDG 12)
- To simulate the models and analyze the results achieved from the various models in terms of heat reduction in the indoors. (SDG 9, SDG 11, SDG 12)
- To evaluate results and derive the shape and material which is most optimum for indoor air temperature reduction. (SDG 9, SDG 11, SDG 12)
- To formulate guidelines for roof design in hot and dry climates to maximize thermal comfort. (SDG 9, SDG 11, SDG 12)

Indeed, its final objective is to develop a roof which has an integration of various techniques and materials. This study would help develop an optimum solution in hot and dry regions to decrease the indoor temperature to a minimum.

Theoretical Framework

Roof Shapes

Traditionally, roof shapes like flat, domed, etc. were used for building construction purposes. Today, although there are many roof shapes available, still these basic shapes are mostly used. These shapes are as follows.

1. Flat roof
2. Semi Circular dome
3. Gable Roof
4. Segmental dome
5. Onion Dome
6. HIP Roof
7. Mansard Roof

8. Gambrel Roof
9. Sloping Roof
10. Vaulted Roof
11. Conical Dome
12. Octagonal Shaped, Ribbed, Florentine Dome
13. Parabolic Dome
14. Hemispherical Dome with Cylindrical base
15. Cloister Dome

Among these shapes, the study concentrates on the following roof types i.e., Semi Circular, Gable, Segmental, Onion and, HIP roof. D. Pearlmutter (1993) states that the roof shapes reveal their performance with respect to hot and dry climate.

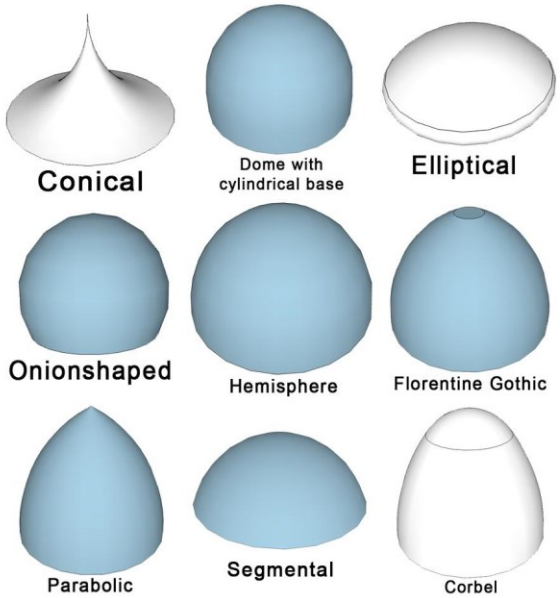

Fig. 1: Different Roof Shapes
Source: Author

Silvayeh et al. (2013) and Suman & Srivastava (2006) have examined roof geometry as a major criterion to determine the thermal performance in buildings. They show that different roof shapes have different effects on the indoor temperature depending on climatic and structural components. The roof shapes affect the indoor air temperature in various ways as follows.

- Through solar radiation.
- Surface area.
- Indoor volume.

The images below show that for flat roofs, the heat gain is not exactly incidental but on a major part of day, it is direct. In the case of pitched roofs, it is incidental on one slope and less effective on the other slopes. However, for the vaulted roofs, it is like pitched roofs, but the heat gain on a non-incidental surface is even less than the pitched roofs. Therefore, it is evident that vaulted roofs are more effective. Vaulted roofs are also like domes, which perform even better as the surface area and angles are more varied as compared to the vaults.

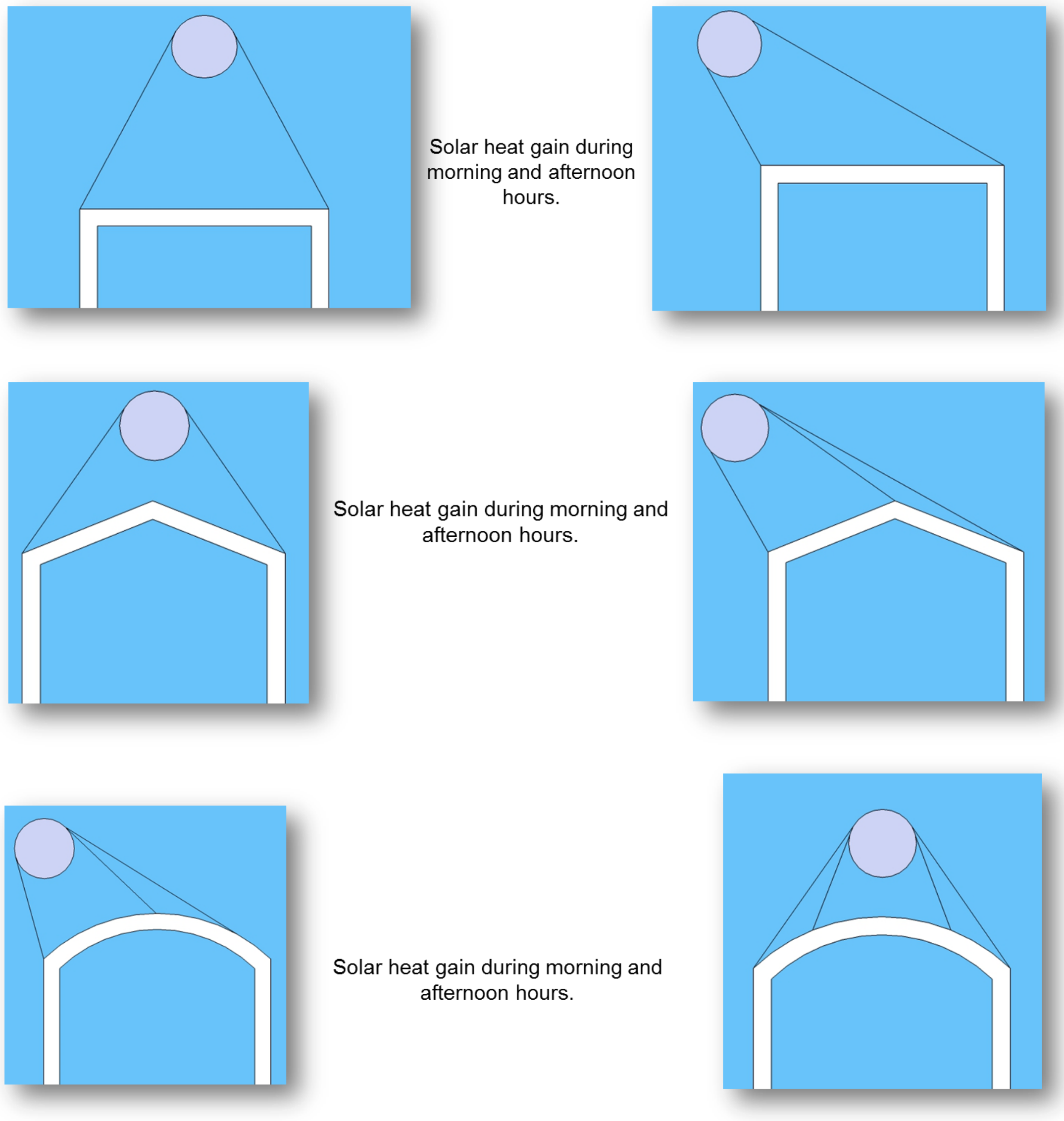

Fig. 2: Comparison of radiation received on various surfaces.
Source: author

Ho (1995) says that as surface area increases, it affects the heat gained through radiation. Amount of radiation is the same and is defined by Watt/m^2. Therefore, it is evident that the area is inversely proportional to radiation. Thus, mathematically speaking, the surface area with regard to the ground area will decide the intensity of radiation. Runsheng, Meir & Etzion (2003) point out that if we consider three structures having the same floor area and different types of roofs with different surface areas of roofs, then the intensity also changes. The surface area of a flat roof will be equal to the floor area, but for a pitched roof, it will be more surface area and for vaulted roof even higher. This added with incident solar radiation helps reduce heat gain in pitched and vaulted roofs compared to with flat roofs.

Lv, et al. (2023) show that indoor volume of any roof type is also governed by the geometry. Different shapes increase the height and this in turn creates a buffer inside the structure which works as a storage for hot air. Simply put, the hot air indoors rises and fills up the uppermost part of the structure. Porras-Amores, Mazarrón & Cañas (2014) study the lower part of the structure and convey that it achieves comfortable conditions till the human height is filled with relatively cooler air. Thus, this thermal bifurcation works better with higher heights indoors.

Roof Materials

Traditionally, materials like stone, brick tiles, etc. were used for building construction purposes. However, today, many materials are utilized in construction purposes, yet these basic ones are still used. These materials are as follows.

1. RCC
2. Bamboo
3. Common Brick – HF-C4
4. Thatch
5. Galvalum Sheet
6. Brick Tile
7. Tensile/ Canvas Sheet
8. Metal
9. Clay/Rammed Earth Roofing
10. Ceramic Tiles
11. Preformed Roof Insulation – IN71
12. Translucent Tiles
13. Glass
14. Ferrocement
15. Slate
16. Terracotta
17. Timber
18. Stone
19. Asphalt Shingles
20. Fiber Tiles
21. Polycarbonate
22. Cavity Blocks
23. Rubber

Among these materials, the study concentrates on the following: i.e., bamboo, red brick, thatch, galvalume sheet, brick tiles, tensile/canvas sheet, metal, clay/rammed earth, ceramic tiles, insulation panels and translucent tiles. A comprehensive detailed table is given below:

Table 1: Specifications of roof materials
Source: IES VE, TRNSYS, SP41 & Research Papers mentioned below.

No.	Materials Name	Conductivity kJ/hmk	Capacity kJ/kg.K	Density kg/m3	Source	U Value W/m2.K	R Value m2.K/W
1	Bamboo	0.64	1.68	765	Shah, D.U., Bock, M.C.D., Mulligan, H. et al. Thermal conductivity of engineered bamboo composites. J Mater Sci 51, 2991–3002 (2016). https://doi.org/10.1007/s10853-015-9610-z	0.77	1.30
2	Common Brick – HF-C4	2.92	0.88	1820	IES VE	2.09	0.48
3	Thatch	0.187	1.67	75	TRNSYS	0.20	4.98
4	Galvalum Sheet	720	0.86	2700	TRNSYS	1.09	0.92
5	Brick Tile	2.8728	0.88	1892	SP41	4.30	0.23

6	Tensile/ Canvas Sheet	0.54	3	1100	Cherunova, I.; Kornev, N.; Lukyanova, E.; Varavka, V. Development and Study of the Structure and Properties of a Composite Textile Material with Encapsulated Heat-Preserving Components for Heat-Protective Clothing. Appl. Sci. 2021, 11, 5247. https://doi.org/10.3390/app11115247	2.70	0.37
7	Metal	0.504	0.9	530	TRNSYS	2.60	0.38
8	Clay/ Rammed Earth Roofing	4.35	0.84	1958	TRNSYS	2.65	0.38
9	Ceramic Tiles	4.32	1	2000	Garcia, Eugenio & Pablos, A. & Bengoechea, M. & Guaita, L. & Osendi, Maria & Miranzo, P.. (2011). Thermal conductivity studies on ceramic floor tiles. Ceramics International - CERAM INT. 37. 369-375. 10.1016/j.ceramint.2010.09.023.	4.72	0.21
10	Preformed Roof Insulation – IN71	0.144	0.8	40	TRNSYS	0.71	1.42
11	Translucent Tiles	0.144	0.84	12	TRNSYS	0.70	1.42

Literature Review

A lot of research has examined the issue of managing heat gain by passive means. Among them Bahadori (1978) and Bencheikh (2013) stand out. For example. according to Bahadori (1978), Pearlmutter (1993), Tang Runsheng, and Meir and Etzion (2003) show that heat gain in terms of radiation/square unit of area is higher for flat roofs. In contrast, heat gain in terms of radiation/square unit of area is lower in the case of domed and vaulted roofs because of their higher surface areas. Heat buildup beneath curved roofs also results in a stratification of the interior air, which improves and increases the comfort of the interior thermal environment. Al-Nuaimi & Al-Madani (2023) examine the building envelopes and their importance in reducing heat gain, typically in hot and dry climate zone. The final concluding remarks were that usage of clay brick, gypsum or plywood lining in the envelope is a brilliant heat gain reducer and performs in the range of 5.5% to 10% related to energy requirement.

Hu et al. (2023) examine passive cooling strategies for residential buildings in hot and dry climate and conclude that building envelope, particularly roof when combined with passive strategies can reduce the indoor air temperature by 2.2°C. The study also finds that this increases the thermal comfort hour by an extended 23%. Similarly, Ho (1995) examines the heat flow through roof and walls using a mathematical model. His findings convey that the thermal inertia of roof is much greater than that of walls and holds a lot of importance for reducing indoor air temperatures in hot and dry climate. Jain, et al. (2018) examine the impact of solar passive cooling techniques in climatic region of Ahmedabad. They conclude that these techniques are very efficient for a place like Ahmedabad and the roofs in particular can contribute significantly to heat gain reduction. Kulkarni & Chandrashekar (2022) examining combining traditional and contemporary roofing solutions to provide optimum heat reducing solution, point out that when traditional methods of passive cooling and thermal comfort attainment are incorporated in contemporary roofs, their performance can increase multifold. But correct understanding of local culture and climate aspects is important for creating viable and sustainable solutions.

Mahdavinejad et al. (2013) look at domed and flat roofs using simulation and say that traditionally, domed roofs have been favorable in reducing indoor air temperature in hot and dry climate. They also focus on the performance of flat roofs, which is still good but domed roofs outperform it due to volume below it. Further, Faghiha & Bahadorib (2009) add that flat roofs with the same base area show a higher heat gain in terms of radiation/square unit of area than the domed roofs. According to them, the total amount of radiation received per unit area is the highest for the flat roofs and the lowest for the St. Peter's dome. Despite this, it is noted that St. Peter's dome receives the largest quantity of radiation overall, whereas flat roofs receive the least amount. In contrast, Ibrahim & Hassan (2023) examine design strategies of traditional build forms and their role in achieving thermal comfort. They conclude that along with other factors in building design, usage of vaulted roof was found out to be optimum in reducing heat gain and providing thermal comfort. The final internal temperature was reduced by 7% in comparison to outdoor temperature.

Satrasala & Manvi (2020) examine different roofs using traditional materials like paper, mud, clay and others. The other components like walls, openings, flooring, etc. are kept constant. They show that clay and mud were able to reduce the temperature of indoors by upto 16°C and the time lag crated by it was 6 hours. Similarly, Arvind & Tiwari (2009) examin the interior air temperature of the New Delhi mud house with a vaulted roof and points out that it ranged from 14^0 to 16^0 degrees Celsius in the winter and from 24^0 to 28^0 degrees Celsius in the summer. The yearly heating and cooling load of the passive house is predicted to be reduced by 1481 and 1813 KWH/year, respectively. Adding to this, Usman (2022) evaluates the effect of roof configuration strategies for indoor thermal comfort in hot and dry climate. He uses a combination of basic roof structure but different material usage strategies and simulate them as a pre build component. Only passive energy efficiency means were used for cooling purposes. He shows that the final roofing unit can actually help in reducing heat gain by 43%.

Faghiha & Bahadorib (2011) however show that under identical conditions, flat and domed roofs perform similarly. However, on warm days, the domed roof is more thermally efficient (42.38^0C compared to 43.90^0C). According to them, if glazed tiles are added to the roof, the interior air temperature of the space beneath the domed roof can be lowered from 42.38^0C to 39.3^0C.

This is affirmed also by Mohammadjavad et al. (2012) who show that 30° and 60° roofs are the best because of their larger volumes and lower unit area %. The results of this investigation however do not support the patterns of sunshine. Kamal (2012), adds to this when he says that vaulted and domed roofs offer better interior thermal conditions since they are quickly cooled down in comparison to flat roofs. Similarly, Sigrid et al. (2013) show that north-light roofs can save up to 54% on energy consumption when compared to a traditional flat roof.

Research Methodology

This research employed a simulation through the following techniques:

- Data Collection
  Data related to building shapes and materials was collected manually from sources like IES VE, TRNSYS, SP41 & Research Papers.
- Simulation software
  Multiple simulation softwares are available for simulating thermal comfort in building. The chosen software i.e. TRNSYS was selected on the basis of its past performance, and application

- Building modelling
  Simulation ready models were developed creating permutations and combinations of building geometry and materials.
- Software simulation
  The model options created are simulated using standard simulation conditions and climate type. The outcome results give the optimum performing roof.

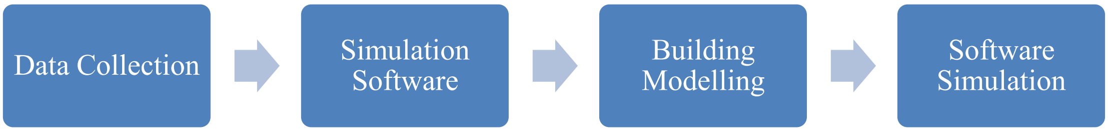

Fig. 3 Methodology Chart
Source: Author

Simulation Software

Before selecting the final simulation software, a few of them were studied. Simulation software considered for in this study are:

a. Therm Version 1.0 (Thermal Evaluation Tool for Buildings)
b. TADSIM (Tools for Architectural Design and Simulation)
c. TRNSYS
d. DOE-2.1E
e. EnergyPlus
f. eQUEST

Selection of Software

This study expects that the simulation would provide an optimum roof structure which integrates techniques, forms and materials for the lowering of indoor air temperature by reducing heat transfer. Therefore**,** TRNSYS, a tool/software for heat transfer simulation was chosen. It is not only popular for scientific and research work and is based on the algorithm modelling, but also is the most reliable tool for such simulations. Multiple research works have used this tool due to its accuracy in results. Study by Jonasa, Lämmleb, Theisc, Schneiderc & Frey (2019) and Vera-García, Rubio-Rubio, López-Belchí & Hontoria (2022) have used TRNSYS as the simulation tool in their study. The final outcome was validated through physical modelling and the results were found to be consistent with the simulation results. ASHRAE has validated the software results in its Standard 140, section 5.2.

Experiment

The investigation for a box type building was conducted using TRNSYS to evaluate the thermal comfort for 8760 hours space operating as non-air-conditioned spaces. All non-AC spaces must comply with the thermal comfort required as per the GRIHA rating system. The analysis of thermal comfort has been detailed in the following section.

Non – air-conditioned Spaces

Thermal comfort is that condition in which a person can maintain equilibrium of body heat at normal temperature without any discomfort. Thermal comfort for naturally ventilated spaces inside a building is incorporated in Criteria 11 of GRIHA v2015 which should be compliant with NBC 2005 requirement.

Achieving Indoor Thermal Comfort Requirements
Commitment for non-air-conditioned space

As per clause 11.1.3: Any project that can acquire the Indian Adaptive Comfort Model or ASHRAE 55 or NBC 2005 thermal comfort standards. These conditions should be for 90% of occupied hours for buildings in moderate, hot & dry, and composite climate. Similar comfort conditions should be available for 60 % of all the occupied hours in warm and humid climate.

Table 2: Desirable wind speeds for thermal comfort conditions
Source: National Building Code of India, 2005

Dry bulb temperature (deg C)	Relative humidity (%)						
	30	40	50	60	70	80	90
28	*	*	*	*	*	*	*
29	*	*	*	*	*	0.06	0.19
30	*	*	*	0.06	0.24	0.53	0.85
31	*	0.06	0.24	0.53	1.04	1.47	2.10
32	0.20	0.46	0.94	1.59	2.26	3.04	**
33	0.77	1.36	2.12	3.00	**	**	**
34	1.85	2.72	**	**	**	**	**
35	3.20	**	**	**	**	**	**
* none ** higher than those acceptable in practice							

Table 3: Roof shapes and types
Source: Author

Sl no.	Building names	Roof typology
1	Type 1	Semi Circular dome
2	Type 2	Gable Roof
3	Type 3	Segmental dome
4	Type 4	Onion Dome
5	Type 5	HIP Roof

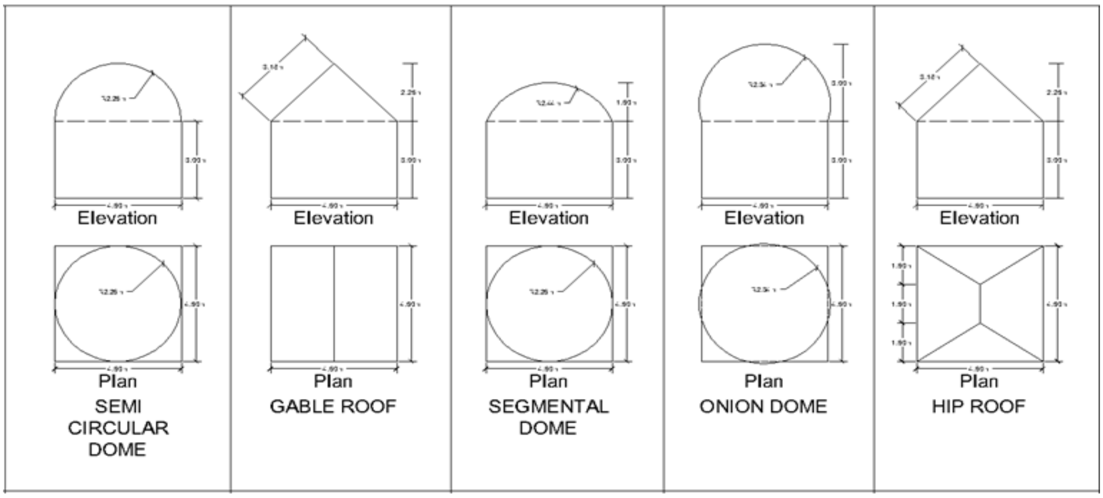

Fig. 4: Geometry of roof shapes
Source: Author

Thermal Comfort Analysis for Non-air-conditioned Spaces

With reference to the above, the non-air-conditioned living area was evaluated for 5 different typologies.

A standard model was developed for a typical room in hot and dry climate region. To study, the city of Jaisalmer in India was chosen. It falls in the climatic region of desert type or hot and dry. The room dimension was kept as 4.0m x 3.0m and the height of the roof was 3.0m. The specifications and details of the built structure are mentioned in Table 5. The simulation was carried out for a time period of one year or 8760 hours i.e., from 01 January till 31 December. The simulation covered DBT and RH for the study. Later, as per ASHRAE Section 55, thermal comfort conditions were added to the software. After making 5 different shapes and 12 material models, data was fed through TRNBUILD and it created a hourly database of comfort level as per ASHRAE standards and the output was 1 in case of comfort and 0 in the case of discomfort. Using an excel sheet, the total was calculated for each model representing a unique material entity. This generated a percentage for each model representing its comfort factor. Higher the percentage, higher will be user comfort.

Table 4: Roof types for the study and details of room space chosen.
Source: Author

Criteria	Details
Zone area for simulation	Full building
Wall Specification	230 mm brick Block
Lighting power density	8 W/m^2
Equipment power density	10 W/m^2
Ventilation Rate	6 air change per hour of outside air
Occupancy schedule	24 hours for 365 days
Occupancy Time	8760 hours annually
Comfort Standard	NBC 2005
Room Size	3.0 m x 4.0 m
Roof Thickness	12 cm with top covering layer
Wall Thickness	230 mm of clay brick with internal plaster of 12 mm cement a external plaster of 12 mm cement
Openings	1.0 m x 1.2 m Window and 1.0 m x 2.1 m Door
Chajja/Overhang	1 each on Window and Door of width 1.5 m x 1.0 m

Findings

Table 5: Results of the simulation.
Source: Author

S. NO.	NAME	ROOF TYPOLOGY	Material 1 Bamboo	Material 2 Red Brick	Material 3 Thatch	Material 4 Galvalum Sheet	Material 5 Brick Tiles	Material 6 Tensile/ Canvas Sheet	Material 7 Metal	Material 8 Clay/ Rammed Earth Roofing	Material 9 Ceramic Tiles	Material 10 Insulation Panel	Material 11 Translucent Tiles	AVERAGE VALUE OF RESULTS
1	Type 1	Semi Circular dome	72.47	71.35	75.40	72.72	67.75	69.69	70.91	70.19	67.42	73.71	73.70	**71.39**
2	Type 2	Gable Roof	74.93	75.83	73.13	74.09	76.61	75.88	74.82	76.42	76.86	73.68	73.70	**75.09**
3	Type 3	Segmental dome	73.98	75.41	72.19	73.41	76.22	75.22	74.16	76.06	76.52	72.89	72.88	**74.45**
4	Type 4	Onion Dome	71.69	70.45	75.56	71.96	66.78	68.89	70.08	69.05	66.42	73.30	73.33	**70.68**
5	Type 5	HIP Roof	73.09	72.35	75.42	73.40	68.84	70.67	71.70	71.44	68.37	74.28	74.29	**72.17**
		AVERAGE VALUE OF RESULTS	**73.23**	**73.08**	**74.34**	**73.12**	**71.24**	**72.07**	**72.33**	**72.63**	**71.12**	**73.57**	**73.58**	

Results shown above were achieved on simulating the models as mentioned above. The table denotes percentage of comfort for each roof shape with respect to material. Higher the percentage, higher is the comfort level.

The results above show that the best combination is a Gable roof having ceramic tiles as the covering material. Its comfort percentage was 76.86%. The lowest performing combination was the Onion dome having ceramic tiles. Its comfort percentage was 66.42%. Interestingly, the best and the worst performing roofs had ceramic tiles as the base material. However, the shape of the roof made all the difference. The best average performing roof shape was found out to be Gable roof at 75.09% and the worst performing roof shape was Onion dome at 70.68%. The best performing roof material was thatch whose average comfort percent was 74.34%, although it wasn't the best performing roof's material. The least performing roof material was ceramic tiles whose average comfort percent was 71.12%, although it was the best performing roof's material.

Conclusion

The simulation produced a total of 55 outcomes, out of which 13 results were higher than 75% in thermal comfort; 33 results fell in the range of 70% - 75% thermal comfort and remaining 09 were below 70% in thermal comfort. Overall range was 66.46% to 76.86%, with a difference of 10.4%. The outcome of the simulations reveals that the shapes and materials chosen for the study are relevant to hot and dry climatic conditions and are capable of achieving good thermal comfort conditions in the indoor spaces.

Although commonly available materials and shapes for hot and dry climates are studied and simulated in this study, many new categories of materials and more complex computer-generated shapes are still not included. At the same time, it must be noted that the simulation is done for the whole year i.e. 8760 hours in a non-leap year. This means that the comfort achieved is not just for summers or hot period of the year but for the colder period too. The comfort is not just for the day time, but the night time as well.

References

Adriaenssens, S., Liu, H., Wahed, M. & Zhao, Q. (2013) Evaluation and Optimization of a Traditional North-Light Roof on Industrial Plant Energy Consumption, Energies, Vol. 6. pp. 1944-1960. doi:10.3390/en6041944.

Al-Nuaimi, S. F. & Al-Madani, W. (2023) Effects of Building Envelopes on Energy Consumption in the Domestic Buildings in Bahrain, ISVS e-journal. pp 166-181.

Alqallaf, H.J., Abu-Arab, T.W. & Alawadhi, E. M. (2012) Experimental Study of a Roof with Cylindrical Holes Containing PCM to Reduce the Heat Gain, Amman, Jordan: Proceedings of the International Conference on Solar energy for MENA region (INCOSOL).

Bahadori, M.N. (1978) Passive cooling system in Iranian architecture, Scientific American, Vol. 238 No. 2. pp 144–154.

Bencheikh, H. (2013) Full scale experimental studies of a passive cooling roof in hot arid areas, International Journal of Renewable Energy Technology Research, Vol. 2 No. 6. pp 170 -180.

Berardi, U., Hosein, A., Hoseini, G. & Hoseini A.G. (2013) State-of-the-art analysis of the environmental benefits of green roofs, Applied Energy, Vol. 115. pp 411–420.

Chel, A. & Tiwari, G.N. (2009) Thermal performance and embodied energy analysis of a passive house – Case study of vault roof mud-house in India, Applied Energy, Vol. 86. pp 1956–1969.

Faghiha, A.K. & Bahadorib, M.N. (2009) Solar radiation on domed roofs, Energy and Buildings, Vol. 41. pp 1238–1245.

Faghiha A.K. & Bahadorib, M.N. (2011) Thermal performance evaluation of domed roofs, Energy and Buildings, Vol. 43. pp 1254–1263.

Ho, D. (1995) Temperature distribution in walls and roofs, Journal of Architecture Engineering, Vol. 01 No. 03. pp 121-132.

Hu, M., Zhang, K., Nguyen, K., & Tasdizen, T. (2023) The effects of passive design on indoor thermal comfort and energy savings for residential buildings in hot climates: A

systematic review, Urban Climate, Elsevier. pp 1-14. DoI: https://doi.org/10.1016/j.uclim.2023.101466.
Ibrahim, H. K. & Hassan, S. A. (2023) Design Strategies Employed to Achieve Thermal Comfort in Traditional Religious Buildings in Iraq, ISVS e-journal. pp 123-135.
Lv L., Wang, X., Zhang, Q., Xiang, Y., Wu, X. & Huang, C. (2023) Investigation of vertical thermal stratification and stratified air conditioning load for large space with low sidewall supply air based on vertical temperature node model, Journal of Building Engineering. DOI: https://doi.org/10.1016/j.jobe.2023.106297.
Jain, D. (2004) Modeling of solar passive techniques for roof cooling in arid regions, Building and Environment, Volume 41, Issue 3. pp 277–287.
Jain, M., Jain, K. & Khare, A. (2018) Climatic Conditions and Design Considerations for Hot and Dry Climate of Ahmedabad, India, International Journal of Research in Engineering, Science and Management. pp 428-432.
Jonasa, D., Lämmleb, M., Theisc, D., Schneiderc, S. & Frey, G. (2019) Performance modeling of PVT collectors: Implementation, validation and parameter identification approach using TRNSYS, Solar Energy. pp 51-64. DOI: https://doi.org/10.1016/j.solener.2019.09.047.
Kamal, M.A. (2012) An Overview of Passive Cooling Techniques in Buildings: Design Concepts and Architectural Interventions, Acta Technica Napocensis: Civil Engineering & Architecture, Vol. 55, No. 1. pp 84-97.
Kulkarni, S. S. & Chandrashekar, M. N. (2022) Parameters for Combination of Contemporary and Traditional Roof Design for Residential Buildings in Hot and Dry Climatic Region in India, International Journal of Engineering Research & Technology. pp 48-51.
Mahdavinejad, M. Ghasempourabadi, M. Nikhoosh, N. & Ghaedi, H. (2012) International Conference on Clean and Green Energy, IPCBEE, vol.27. pp. 62-66.
Mahdavinejad, M., Badri, N., Fakhari, M. & Haqshenas, M. (2013) The Role of Domed Shape Roofs in Energy Loss at Night in Hot and Dry Climate, American Journal of Civil Engineering and Architecture. pp 117-121. DOI: 10.12691/ajcea-1-6-1.
Neymark, J., Judkoff, R., Kummert, M. & Muehleisen, R. (2020) Update of ASHRAE Standard 140 Section 5.2 and Related Sections (BESTEST Building Thermal Fabric Test Cases), USA: Argonne National Laboratory.
O¨ zdeniz, M.B. & Hanc¸er, P. (2004) Suitable roof constructions for warm climates—Gazimag˘usa case, Energy and Buildings, Vol. 37. pp 643–649
Pandey, S. Pandey, R. & Hindoliya, D.A. (2012) Cooling Load Reduction using insulator over the roof of buildings, American Journal of Sustainable Cities and Society, Vol 1, Issue 1. pp 45-53.
Pearlmutter, D. (1993) Roof geometry as a determinant of thermal behavior – a comparative study of vaulted and flat surface in a hot-arid zone, Architectural Science Review, Vol 36 No. 2. pp 75–86.
Plumbe, W.J. (1987). Climate as a factor in the planning of university library buildings. Tropical Librarianship, New York: Metuchen. pp 19-52.
Porras-Amores, C., Mazarrón, F. & Cañas, I (2014). Study of the Vertical Distribution of Air Temperature in Warehouses, Energies. pp 1193-1206. DOI: 10.3390/en7031193.
Rodriguez, N.J., Ya˜nez-Limon, M., Gutierrez-Miceli, F.A., Gomez-Guzman, O., Matadamas-Ortiz, T.P., Lagunez-Rivera, L. & Feijoo, J.A.V. (2010) Assessment of coconut fibre insulation characteristics and its use to modulate temperatures in concrete slabs with the aid of a finite element methodology, Energy and Buildings, Vol. 43. pp 1264–1272.
Runsheng, T., Meir, I.A. & Etzion, Y. (2003) An analysis of absorbed radiation by domed and vaulted roofs as compared with flat roofs, Energy and Buildings, Vol. 35. pp 539–548.
Satrasala, V. & Manvi, N. (2020) Comparative Analysis of Thermal Performance of Roof Component using Alternative Materials Taking case of Hot and Dry Climatic Condition of Bhuj-Kutch, International Journal of Innovative Science and Research Technology. pp 657-667.
Silvayeh, S., Mahdavinejad, M., Taheri, H. & Badri, N. (2013) Establishment of Optimum Designing Pattern in Buildings Roofs Shapes to Achieve Heating Energy Efficiency:

Architectoni.ca, Vol.2. pp 42-51. DOI:http://ccaasmag.org/ARCH, DOI:10.5618/arch.v2.5.
Suman, B.M. & Srivastava, R.K. (2006) Influence of thermal insulation on conductive heat transfer through roof ceiling construction, Journal of Scientific & Industrial Research, Vol. 68. pp 248 – 251.
Teixeira, C.F.B. & Labaki, L.C. (2013) Study of Thermal Behaviour of Roofing on Subtropical Climate - The Use of Radiant Barrier. International Journal of Renewable and Sustainable Energy, Vol. 2, No. 1. pp 12-17. DOI: 10.11648/j.ijrse.20130201.12.
Usman, A. M. (2022) Effect of Roof Configurations on Temperature and Thermal Comfort on Residential Homes in Hot Dry Climate of Bauchi, Nigeria, International Journal of Engineering Research and Applications. pp 123-136. DOI: 10.9790/9622-1210123136.
Vera-García, F., Rubio-Rubio, J.J., López-Belchí, A. & Hontoria, E. (2022) Modelling and real-data validation of a logistic centre using TRNSYS: Influences of the envelope, infiltrations and stored goods, Energy & Buildings. pp 1-16. DOI: https://doi.org/10.1016/j.enbuild.2022.112474.
Vijaykumar, K.C.K., Srinivasan, P.S.S. & Dhandapani, S. (2005) A performance of hollow clay tile (HCT) laid reinforced cement concrete (RCC) roof for tropical summer climates, Energy and Buildings, Vol. 39. pp 886–892.
Vorster, J. & Dobson, R. (2011). Sustainable cooling alternatives for buildings, Journal of Energy in Southern Africa, Vol 22 No 4. pp 48-66.
Zhang, Y., Zhou, G., Lin, K., Zhang, Q. & Di, H. (2007) Application of latent heat thermal energy storage in buildings – State-of-the-art and outlook, Building and Environment, Volume 42 Issue 6. pp 2197–2209.