

## The influence of attics space geometrical shape on ignition and flashover stages in residential building fires in dense settlements

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ARTICLE INFO	ABSTRACT
<p><i>Article history:</i> Received November 18, 2022 Received in revised form Dec. 04, 2022 Accepted December 12, 2022 Available online December 31, 2022</p> <p><i>Keywords:</i> Attic Dense settlements Residential house Space</p> <p><b>*Corresponding author:</b> Amat Rahmat Department of Architecture, Faculty of Civil Engineering and Planning, Universitas Kebangsaan Republik Indonesia Email: <a href="mailto:amatrahmat.saja@gmail.com">amatrahmat.saja@gmail.com</a> ORCID: <a href="https://orcid.org/0000-0001-7465-1816">https://orcid.org/0000-0001-7465-1816</a></p>	<p><i>As an artificial physical place, residential building is formed by various functional spaces, such as residential space and the space between the ceiling space and the roof, i.e. the attics. The phenomenon of fires in residential buildings in densely populated areas is suspected of having occurred in the attics. Hitherto, research on the fire space model concerning the stages of ignition and flashover usually employs the Steckler's compartment model in the form of a cube/box. On the contrary, the fire model with a triangular roof shape is still rarely studied. The purpose of this study was to analyse the influence of the geometric shape of the attics on the ignition and flashover stages in residential fires located in densely populated settlements. This study employs an experimental method by conducting scaled experiments of the geometric model of the ceiling space in the form of a triangular gable roof and shed roof, focusing on the ignition and flashover stages. The results showed that the ignition stage in the gable roof and shed roof models occurred in the 3rd and 4th minutes with a temperature ranging from 270 °C - 476 °C. The flashover stage also occurred in the 5th to 9th minute with regular results close to 500 °C.</i></p>

### Introduction

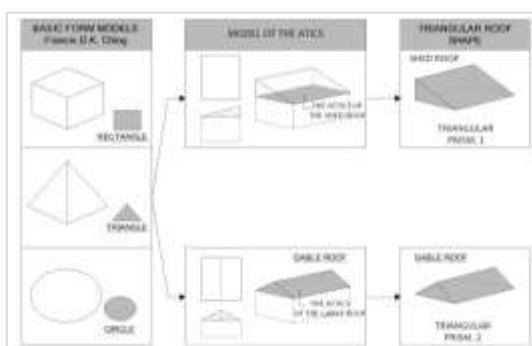
Adaptation of traditional Indonesian architectural forms appears in the design of the geometric model of the roof. In contemporary architectural practice, triangular roof forms such as gables, shed roofs, as well as hip roof are widely used. In line with these forms, there is a tendency to turn the space between the roof and the ceiling, i.e., the attics, into a sleeping area or warehouse (figure 1) (Rahmat, Prianto, and Sasongko 2017). This

adjustment was made without regard to building safety and life safety standards.

The development of basic form of the geometric model of the attics is formed from various combinations of several fields as the boundaries of the lower space and the roof of the building. The development of the geometric shape of the attics is more identical to the basic triangular prism shape. This form is very commonly used on roofs in Indonesia. The triangular prism shape development model can be seen in (figure 2).



**Figure 1.** The attics were converted to a warehouse in the residential building in Cicadas, Bandung City



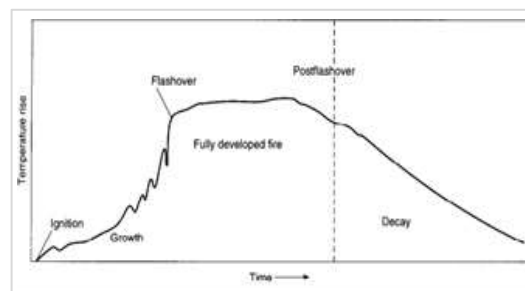
**Figure 2.** Geometric model of the attics in a prism and pyramid shape (Ching 2014)

Residential fires in dense urban settlements are currently common and are a part of urban problems. According to the Fire and Rescue Service, through 2021 alone, there have been 17,168 fire incidents in Indonesia, most of which occurred in densely populated residential areas due to electrical short circuits, totalling 5,274 incidents (CNN Indonesia 2021).

The cube shape of the Steckler's compartment theory is still often used for the study of experimental methods, both with scaled experiments and with simulations (Steckler, Quintiere, and Rinkinen 1982). Recently, researchers have been increasingly using experimental studies with scalable modelling. Scalable modelling can allow for fire investigations and replicating the dynamics of specific fires to reduce costs dramatically (Quintiere et al. 2017). The development of a fire model in a scalable experiment on fire behaviour arises from an assessment of methodology, complexity, incompatibility, and uncertainty (Torero 2013).

Research on the stages of fire in the geometric shape of a triangular space, such as the attics, is

rarely carried out. In fact, an understanding of fire behavior in an enclosed space has a strategic element in efforts to protect fires, especially in the development of fire protection system designs (Drysdale 2011). This is shown through the pattern of fire growth which is expressed in temperature variations during the time of the fire (figure 3).



**Figure 3.** General description of room fire in absence of fire control (Walton, Thomas, and Ohmiya 2016)

Fires in confined spaces are a highly complex problem because it is difficult to describe or predict how they will behave (Hutomo, Ekomadyo, and Ameir 2020; Dwisusanto and Hermawan 2020; Mvogo et al. 2022). A fire in a corner room with two dividing walls will spread more quickly and be more intense than a single-wall fire (Zeinali et al. 2018). Thus, real-time forecasting of building fire developments and critical fire events is essential for firefighting and rescue operations (T. Zhang et al. 2022).

The discussion on fires is inseparable from the stages of the fire behaviour itself, namely the ignition stage, i.e. the process of controlling continuous combustion by itself (self-sustaining), the growth stage, the full fire stage (flashover) and the receding stage (Friedman 1998). At the ignition stage, the temperature reaches 250 °C with achievement of less than 5 minutes and the flashover achievement stage, depending on the variable fuel characteristics, chamber volume and ventilation size, can be achieved in a matter of 5 to 15 minutes (Patterson 1993), whereas according to NFPA 555 (2021) for the flashover time to occur from 7 to 10 minutes. The flashover stage of the closed chamber testing of the Stekler model occurs at temperatures approaching 500 °C and even reaching 1000 °C. The process of burning in an enclosed space from the ignition stage to the flashover stage is influenced by several factors, including the geometric shape of the space (Lirola et al. 2017).

It has been described that research related to the geometric model of the ceiling space in the form of a triangular roof still tends to be rarely carried out, compared to the cubic space model of the Steckler model. The fire in the attics started with an electrical short circuit. From the comparison of the two geometric models of the gable roof and the shed roof, an assessment will be carried out to determine whether the gable roof shape model will take longer to the onset of ignition and flashover than the shed roof; or vice versa.

Based on the research problem, the purpose of this research is to analyse the influence of the geometric model of the attic on the ignition and flashover stages. In line with the phenomenon, this study focused on the residential buildings located in densely populated settlements.

According to [Cvetković et al. \(2022\)](#), the various causes of the high risk of fire disasters for residential buildings are the lack of preventive measures related to building technology knowledge, the high cost of equipment, or not knowing the right actions to take. Therefore, this research provides a significant overview of how to reduce the risk or impact of fire in residential buildings. This study's results can contribute to optimising the geometric model design of the attics in developing a test chamber model of gable and shed roofs that can minimise the occurrence of ignition and flashover of the stages of fire. Hence, it could provide input to complement standards and guidelines for fire prevention systems in residential building design.

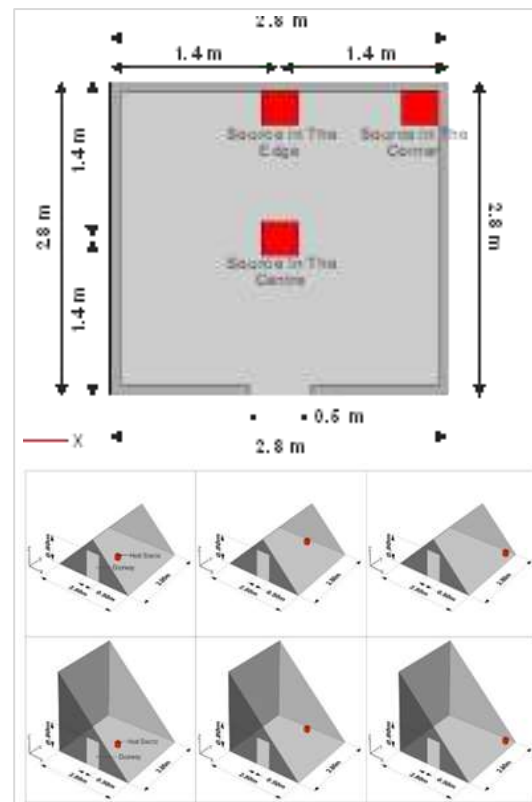
## Method

This research will focus on experimental methods with scaled experiments. The scale experiment was carried out at the fire laboratory owned by the Cileunyi Research Center for Research and Development, West Java. The stages, limitations and variables in this research method can be described as follows:

- a. Making a geometric model according to Steckler compartment model. This model measuring 2.8 x 2.8 m, and would be tested with a scaled experiment. Only one aperture in the model is selected. The fire source model is selected from an electric short circuit according to the causes of fires in residential houses in dense settlements. Empirical

observation shows that most of the residential building in densely populated settlements use wood material as enclosure elements. Moreover, previous research also shows that the commonly used wood materials is a safety challenge for building design, especially for fire prediction and control ([Y. Zhang and Wang 2021](#)). In order to mimic the empirical condition and gain a more accurate result, this model is made using wood material.

The location of fire points in the test room is placed at three points, namely the centre, edges and corners of the attics, identical to the connection system for lights and sockets in the arrangement of electrical installations in the ceiling space. The roof has a slope angle of 45°. The vent is placed on the outside. To measure the temperature, a thermocouple cable was installed inside the test chamber model ([figure 4](#)).



**Figure 4.** Geometric design model of the attic space to be tested

- b. Making a triangular attic model to be studied in a scaled experiment ([figure 5](#))



**Figure 5.** Scaled models of a gable roof (above) and shed roof (below)

- c. Measurement of ambient temperature inside and outside the test chamber of the gable and shed roof models, to obtain primary data at the site (figure 6).



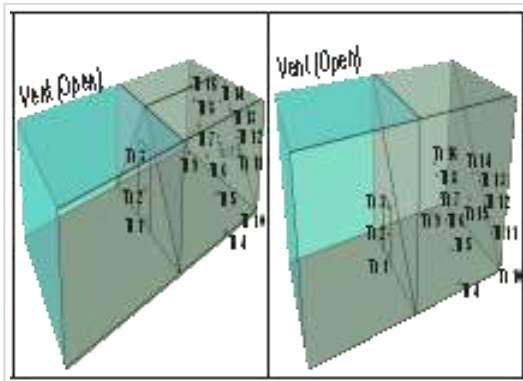
**Figure 6.** Measuring implementation of ambient temperature in the model room

- d. The installation of the thermocouple cable on the Hi-Logger device is carried out according to the measuring point marked on the space in the test model (figure 7).



**Figure 7.** Installation and testing of Hi-Logger equipment

- e. Placement of thermocouple measurement points and the location of the fire source on the geometric model of the ceiling space in the form of a triangular gable roof. To provide comprehensive data about the combustion temperature in the Hi Logger tool, 16 points are determined (figure 8 and table 1).



**Figure 8.** Placement of thermocouple and vent measuring points on the test model

**Table 1.** Determining the location of the measuring point on the thermocouple and the fire sources

Point name	Z (m)	Y (m)	X (m)
Fire location in the centre	0,15	1,4	1,4
Fire location in the edge	0,15	1,4	2,7
Fire location in the corner	0,15	2,7	2,7
Measuring point T1	0,08	1,4	2,7
Measuring point T2	0,37	1,4	2,44
Measuring point T3	0,57	1,4	2,24
Measuring point T4	0,04	0,2	1,4
Measuring point T5	0,36	0,2	1,4
Measuring point T6	0,51	0,2	1,4
Measuring point T7	0,85	1,4	1,4
Measuring point T8	1,35	1,4	1,4
Measuring point T9	1,2	1,4	1,4
Measuring point T10	0,9	2,7	1,4
Measuring point T11	0,59	2,7	1,4
Measuring point T12	0,35	2,7	1,4
Measuring point T13	0,04	1,4	0,05
Measuring point T14	0,3	1,4	0,33
Measuring point T15	0,55	1,4	0,58
Measuring point T16	0,8	1,4	0,85

f. Preparing the equipment that will be used in the scaled experiment (figure 9)



List of equipment:

1. Thermocouple wire;
2. Hi-Logger tool;
3. Infrared temperature digital device;
4. Measuring tool;
5. Non-standard Stranded cable;
6. Single cable;
7. Stopwatch;
8. Digital cameras;
9. Go-pro camera;
10. FLIR digital temperature.

**Figure 9.** Equipment used for scaled experiment activities

The variables in this study are as follows:

- a. Independent variable
  - shape of the attic on gables and mono-pitch roof;
  - fire source.
- b. Dependent variable
  - temperature (°C);
  - duration of fire (time/minute);
  - area of the base of the test model (length x width);
  - slope angle of test model (45°);
  - openings.

## Result and discussion

Scaled experimental testing on the geometric model of the attic in the form of a triangular gable roof and the mono-pitch roof. Scale trials on the triangular gable roof and mono-pitch for the stages of ignition and flashover were carried out by placing three locations of fire sources, namely the centre, edges, and corners. Data from the Hi-Logger and FLIR tool settings were obtained from direct measurements at the test location, such as the average ambient temperature

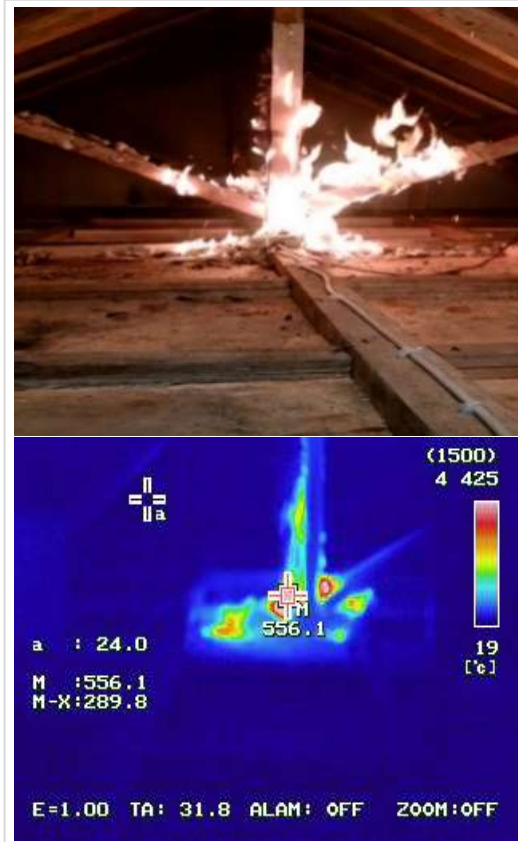
measurement results at 29 °C in sunny conditions. The temperature limits at the ignition stage were taken from secondary data from previous studies, namely 250 °C and flashover temperatures of 500 °C–600 °C.

The results of a scaled experimental test on a geometric model of a triangular gable ceiling space with a class C fire model (NFPA 01 2021; NFPA 555 2021) were as follows:

- a. Testing the gable roof model for the ignition and flashover stages (figure 10 and 11). The fire source is located at the centre of the room. The test was carried out on May 24th 2018 at 02:00 p.m.



**Figure 10.** Analysis result of the gable roof model, with the fire source located at the centre of the room. The ignition stage began at 02.05 p.m. with a temperature of 270 °C. Ignition occurs in the 4th minute



**Figure 11.** Analysis result of the gable roof model, with fire source located at the centre of the room. The flashover stage started at 02:06 p.m. with a temperature of >500 °C. The flashover stage occurs in the 6th minute

- b. Testing the gable roof model for the ignition and flashover stage (figure 12 and figure 13). The fire source located at the edge of the room. The test was carried out on May 25th 2018 at 09:17 a.m.



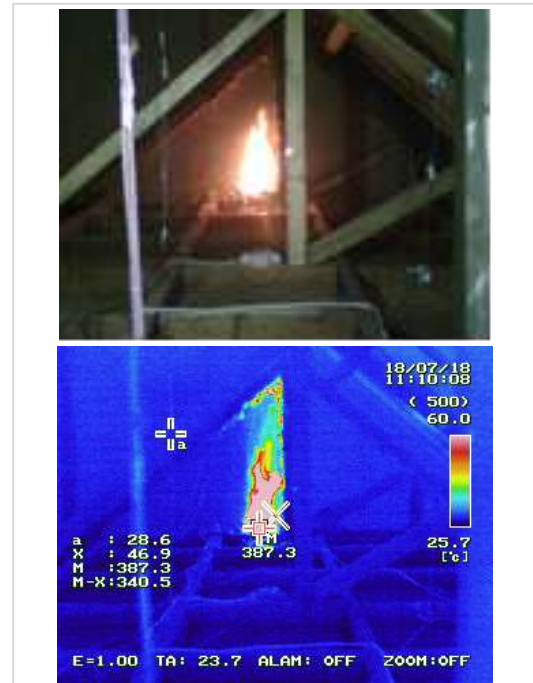


**Figure 12.** Analysis result of the gable roof model, with the fire source located at the edge. The ignition stage began at 09:23 a.m. with a temperature of 252 °C. Ignition occurred in the 6th minute

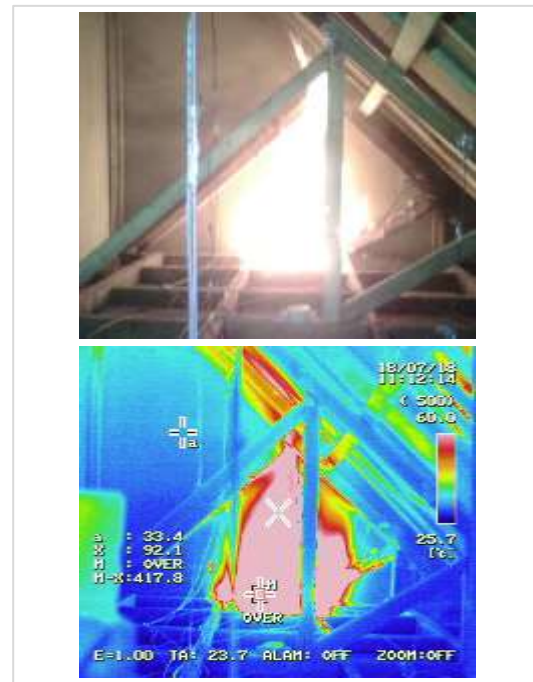


**Figure 13.** Analysis results of the gable roof model, with the fire source located at the edge. The flashover stage started at 09:26 a.m. with a temperature of >500 °C. Flashover occurred in the 9th minute

c. Testing the shed roof model with the fire source located at the edge of the room (figure 14 and figure 15). The test was carried out on July 18th 2018, at 11.06 a.m.

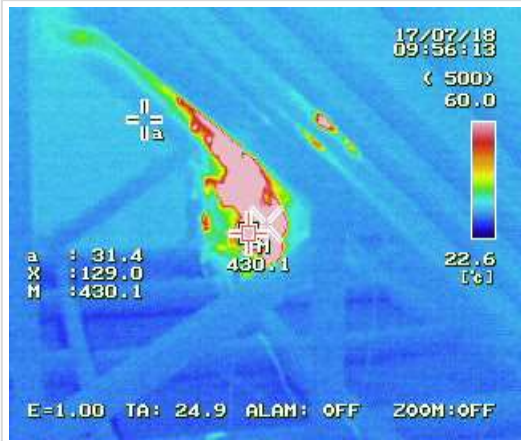


**Figure 14.** Analysis result on the shed roof model, with the fire source located at the edge. The ignition stage began at 11:10 a.m. with a temperature of 387 °C. Ignition occurred in the 4th minute

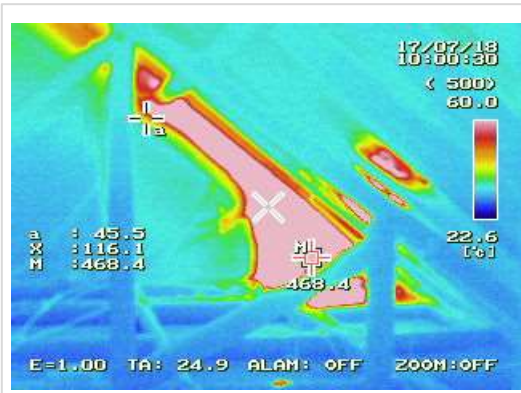


**Figure 15.** Analysis result on the shed roof model, with the fire source located at the edge. The flashover stage began at 11:12 a.m. with a temperature >500 °C. Flashover time occurs in the 6th minute

- d. Testing the shed roof model with the fire source located in the corner of the room (figure 16 and figure 17). The test was carried out on July 17th 2018, at 09.52 a.m.



**Figure 16.** Analysis results of the shed roof model, with the fire source located in the corner of the room. Ignition stage began at 09:56 a.m. with a temperature of 430 °C. Ignition occurred in the 4th minute

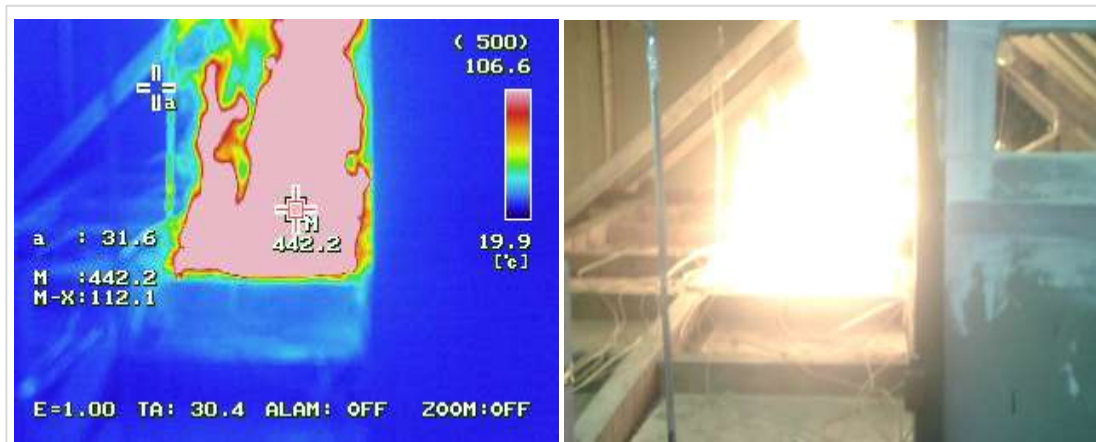


**Figure 17.** Analysis result of the shed roof model, with the fire source located in the corner of the room. The flashover stage began at 10.02 a.m. with a temperature of >500 °C. Flashover occurred in the 6th minute

- e. Testing the shed roof model with the fire source located in the centre of the room (figure 18 and figure 19). The test started on July 11th 2018, at 11:00 a.m.



**Figure 18.** Analysis result of the shed roof model, with the fire source located in the centre of the room. The ignition stage began at 01:02 p.m. with a temperature of 442 °C. Ignition occurred around the 3rd minute



**Figure 19.** Analysis result of the shed roof model, with the fire point located in the centre of the room. The flashover stage began at 11:04 a.m. with a temperature of >500 °C. The flashover occurred around the 5th minute

Based on the analysis results, it could be seen that the slowest time of flashover occurred in the shed roof model, with the fire source located at the edge of the room. The slowest time for the

gable roof model towards the ignition stage occurred in the 6th minute, and the flashover stage occurred in the 9th minute (table 2).

**Table 2.** Scaled experiments results on both gable and shed roof models

Geometrical shape of the attics	Fire point location	Time and temp-ignition		Time and temp- flashover	
		Temp (°C)	t (minute)	Temp (°C)	t (minute)
Gable roof	Centre	270°C	4	> 500°C	6
	Edge	252°C	6	> 500°C	9
	Corner	312°C	4	> 500°C	6
Shed roof	Centre	476°C	3	> 500°C	5
	Edge	387°C	4	> 500°C	6
	Corner	468°C	4	> 500°C	6

Analysis of changes in temperature rise in the attic space due to differences in the geometric shape of the roof and the location of the fire source based on the formulation of [Steckler, Quintiere, and Rinkinen \(1982\)](#); and [Lemmertz \(2019\)](#):

$$\Delta T = \frac{0.22 [k \cdot Q]^{2/3}}{H^{5/3}}$$

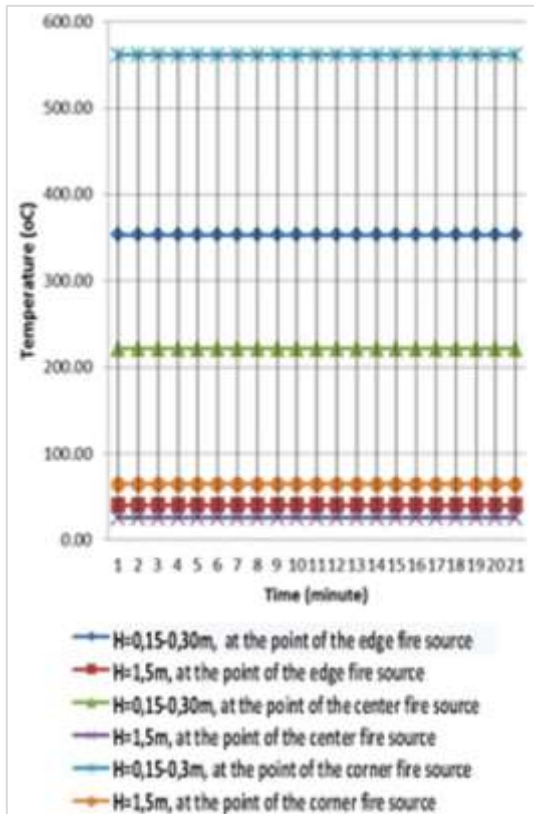
$\Delta T$ : maximum rise of temperature (K) above ambient

Q: total heat release rate (W), provided that:  
 K: 1, when there is no wall nearby  
 K: 2, for the fire source located at the center  
 K: 3, for the fire source located at the edge  
 K: 4, for the fire source located at the corner  
 H: distance (m) above the top of the fuel pack

Test results on the gable roof and shed roof models showed that the maximum rise of temperature of ambient ( $\Delta T_g$ ) has the same value, regardless of the location of the fire source.

**Table 3.** The maximum temperature rises above the ambient temperature ( $\Delta T_g$ ) in the gable roof and shed roof models

$\Delta T_g = ((0.22[kQ]^{0.67}) H^{1.67})$ Edge fire point in the shed roof and gable roof model		$\Delta T_g = ((0.22[kQ]^{0.67}) H^{1.67})$ Centre fire point in the shed roof and gable roof model		$\Delta T_g = ((0.22[kQ]^{0.67}) H^{1.67})$ Corner fire point in the shed roof and gable roof model	
H = 0,15-0,30m	H = 1,5m	H = 0,15-0,30m	H = 1,5m	H = 0,15-0,30m	H = 1,5m
$\Delta T_g = 352,8 \text{ } ^\circ\text{C}$	$\Delta T = 40,4 \text{ } ^\circ\text{C}$	$\Delta T_g = 25,4 \text{ } ^\circ\text{C}$	$\Delta T = 25,4 \text{ } ^\circ\text{C}$	$\Delta T_g = 561,3 \text{ } ^\circ\text{C}$	$\Delta T = 64,3 \text{ } ^\circ\text{C}$



**Figure 20.** The maximum temperature rise above the ambient temperature ( $\Delta T_g$ ) in the shed roof model from various fire points

Of the two geometric model of the attic, the shed roof and gable roof with the fire point at the corner gives the highest  $\Delta T_g$  value (561.4 °C for  $H= 0.15 - 0.30$  m, and 64.3 °C for  $H= 1.5$  m) compared to other fire points. The fire point of the  $\Delta T_g$  value is at the middle level (352.8 °C for  $H=0.15-0.30$  m, and 40.4 °C for  $H=1.5$  m), and the lowest level is at the centre fire source (221.8 °C for  $H=0.15-0.30$  m, and 25.4 °C for  $H=1.5$  m). From the calculation above, the influence of the geometry of the attic does not affect the value of  $\Delta T_g$ . Both types of roof, i.e. the gable and shed roof, have the same  $\Delta T_g$  value.

Based on the rise of the temperature that occurred in the scaled experiments, the fire behaviour on a gable roof with the fire point located at the edge has a slower ignition and flashover stage than on a shed roof. Using models to predict ignition and flashover provides an overview of fire phenomena in various roof shapes and attics (Fu et al. 2021). The location of the fire point in a specific space will also result in differences in combustion properties. This

knowledge could be helpful in providing design decisions regarding the shape of the roof, as well as optimising the design of the geometric model of the attics, which can reduce the risk of threats from the impact of the fire itself (Kodur, Kumar, and Rafi 2020).

## Conclusion

This study concluded that the ignition stage of the gable and shed roof models began at a temperature of 250 °C in the 3rd minute, regardless of the location of the fire source. In the shed roof model, the temperature spike occurs faster than in the gable roof model. In line with the theory of Steckler, Quintiere, and Rinkinen (1982); Patterson (1993); NFPA 01 (2021); and NFPA 555 (2021), that the ignition stage will occur in less than 5 minutes with a temperature close to 250 °C and the flashover stage will occur in 5 to 15 minutes with a temperature reaching close to 500 °C, the results of scaled experiments shows that the ignition stage for both gable and shed roof model occurred in the 3rd and 4th minute with a temperature range of 270 °C-476 °C, and for the flashover stage both occur in the 5th to 9th minute with a temperature close to 500 °C.

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## References

- Ching, Francis D. K. 2014. *Architecture: Form, Space, and Order*. 4th ed. Hoboken, New Jersey: John Willey and Sons.  
<https://archive.org/details/architecture-form->

- space-and-order-4th-edition-pdfdrive/page/n5/mode/2up.
- CNN Indonesia. 2021. '17.768 Kebakaran Di 2021, 5.274 Di Antaranya Akibat Korsleting'. Cnnindonesia.Com. 2021. <https://www.cnnindonesia.com/nasional/20220301134907-20-765357/17768-kebakaran-di-2021-5274-di-antaranya-akibat-korsleting#:~:text=Sebanyak 17.768 kasus kebakaran terjadi,kejadian kebakaran di seluruh Indonesia.>
- Cvetković, Vladimir M., Aleksandar Dragašević, Darko Protić, Bojan Janković, Neda Nikolić, and Predrag Milošević. 2022. 'Fire Safety Behavior Model for Residential Buildings: Implications for Disaster Risk Reduction'. *International Journal of Disaster Risk Reduction* 76 (June): 102981. <https://doi.org/10.1016/j.ijdr.2022.102981>.
- Drysdale, Dougal. 2011. *An Introduction to Fire Dynamics*. 3rd ed. Chichester [West Sussex]: Wiley. <https://doi.org/10.1002/9781119975465>.
- Dwisusanto, Yohanes Basuki, and Hermawan. 2020. 'The Role and Meaning of Fireplace in Karangtengah Hamlet Settlement, Banjarnegara: A Study of the Spatial Pattern of Pawon and Kinship'. *ARTEKS: Jurnal Teknik Arsitektur* 5 (3): 479–88. <https://doi.org/10.30822/arteks.v5i3.609>.
- Friedman, Raymond. 1998. *Principles of Fire Protection Chemistry and Physics*. 3rd ed. Quincy, Massachusetts, U.S: National Fire Protection Association.
- Fu, Eugene Yujun, Wai Cheong Tam, Jun Wang, Richard Peacock, Paul A Reneke, Grace Ngai, Hong Va Leong, and Thomas Cleary. 2021. 'Predicting Flashover Occurrence Using Surrogate Temperature Data'. *Proceedings of the AAAI Conference on Artificial Intelligence* 35 (17): 14785–94. <https://doi.org/10.1609/aaai.v35i17.17736>.
- Hutomo, Cahyo, Agus Ekomadyo Ekomadyo, and Muchi Juma Ameir. 2020. 'Mandate (Credential) as Mitigation Culture on Local Community of Sindang Barang'. *ARTEKS: Jurnal Teknik Arsitektur* 5 (1): 101–14. <https://doi.org/10.30822/arteks.v5i1.283>.
- Kodur, Venkatesh, Puneet Kumar, and Muhammad Masood Rafi. 2020. 'Fire Hazard in Buildings: Review, Assessment and Strategies for Improving Fire Safety'. *PSU Research Review* 4 (1): 1–23. <https://doi.org/10.1108/PRR-12-2018-0033>.
- Lemmertz, Calisa Katuscia. 2019. 'Improved Correlations for Predicting Hot Gas Layer Temperature in a Pre-Flashover Compartment Fire Considering Heat Source Location'. UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL. <https://lume.ufrgs.br/bitstream/handle/10183/197076/001095937.pdf?sequence=1&isAllowed=y>.
- Lirola, Juan M., Estéfana Castañeda, Benito Lauret, and Mohamed Khayet. 2017. 'A Review on Experimental Research Using Scale Models for Buildings: Application and Methodologies'. *Energy and Buildings* 142 (May): 72–110. <https://doi.org/10.1016/j.enbuild.2017.02.060>.
- Mvogo, Philippe Onguene, Olivier Zatao Samed, Patrice Changement, Justin Tégawendé Zaida, Wolfgang Nzie, Henri Ekobena Fouda, and Ruben Mouangue. 2022. 'Investigative Study on Convective Heat Transfer inside Compartment during Fire Situation'. Edited by Sergey M. Frolov. *Journal of Combustion* 2022 (July): 1–12. <https://doi.org/10.1155/2022/6559812>.
- NFPA 01. 2021. 'Fire Code'. NFPA National Fire Codes. 2021. <http://codesonline.nfpa.org>.
- NFPA 555. 2021. 'Guide on Methods for Evaluating Potential for Room Flashover'. NFPA National Fire Codes. 2021. <http://codesonline.nfpa.org>.
- Patterson, James. 1993. *Simplified Design for Building Fire Safety*. New York: Wiley.
- Quintiere, J.G., Allison C. Carey, Lenwood Reeves, and Lee K. McCarthy. 2017. 'Scale Modeling in Fire Reconstruction'. United States. <https://www.ojp.gov/pdffiles1/nij/grants/250920.pdf>.
- Rahmat, Amat, Eddy Prianto, and Setia Budi Sasongko. 2017. 'Studi Pengaruh Penutup Atap Terhadap Kondisi Termal Pada Ruang Atap'. *Jurnal Arsitektur ARCADE* 1 (1): 35. <https://doi.org/10.31848/arcade.v1i1.12>.
- Steckler, K.D., J.G. Quintiere, and W.J. Rinkinen. 1982. 'Flow Induced by Fire in a Compartment'. *Symposium (International) on Combustion* 19 (1): 913–20.

- [https://doi.org/10.1016/S0082-0784\(82\)80267-1](https://doi.org/10.1016/S0082-0784(82)80267-1).
- Torero, José L. 2013. 'Scaling-Up Fire'. *Proceedings of the Combustion Institute* 34 (1): 99–124. <https://doi.org/10.1016/j.proci.2012.09.007>.
- Walton, William D., Philip H. Thomas, and Yoshifumi Ohmiya. 2016. 'Estimating Temperatures in Compartment Fires'. In *SFPE Handbook of Fire Protection Engineering*, 996–1023. New York, NY: Springer New York. [https://doi.org/10.1007/978-1-4939-2565-0\\_30](https://doi.org/10.1007/978-1-4939-2565-0_30).
- Zeinali, Davood, Steven Verstockt, Tarek Beji, Georgios Maragkos, Joris Degroote, and Bart Merci. 2018. 'Experimental Study of Corner Fires—Part I: Inert Panel Tests'. *Combustion and Flame* 189 (March): 472–90. <https://doi.org/10.1016/j.combustflame.2017.09.034>.
- Zhang, Tianhang, Zilong Wang, Ho Yin Wong, Wai Cheong Tam, Xinyan Huang, and Fu Xiao. 2022. 'Real-Time Forecast of Compartment Fire and Flashover Based on Deep Learning'. *Fire Safety Journal* 130 (June): 103579. <https://doi.org/10.1016/j.firesaf.2022.103579>.
- Zhang, Yongwang, and Lu Wang. 2021. 'Research on Flashover Prediction Method of Large-Space Timber Structures in a Fire'. *Materials* 14 (19): 5515. <https://doi.org/10.3390/ma14195515>.