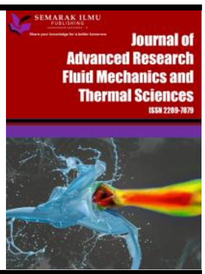
SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



The Analysis of Building Thermal Comfort based on Air Flow Pattern by using SIMSCALE Simulation

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ARTICLE INFO

Article history:
Received 27 June 2024
Received in revised form 19 October 2024
Accepted 27 October 2024
Available online 10 November 2024

Keywords:
Thermal comfort; air flow pattern; SIMSCALE simulation

ABSTRACT

Thermal condition is one of the most important elements of comfort, which can affect people's activities and working circumstances. Thermal comfort in a room can be controlled by improving the quality of ventilation and designing air flow. This study aims to determine the thermal comfort of a building by using simulation. The data used are building design specification, air temperature, and air flow pattern. The simulation input variables are the 3D model of the room design, maximum and average air temperatures and average air flow velocity values. The expected simulation output are air temperature contour data and air flow patterns. These two values of output are then compared with Indonesia's national standard SNI 03-6572-2001 and subjective reactions to determine comfort in the rooms. The results show that based on the air temperature contour, the wider the room the air temperature tends to be in a comfortable condition. It also shows that the ratio of the opening area to the floor area can influence the cooling of the air temperature in the room. Based on the flow pattern air, openings facing each other in a room will improve air circulation and it is influenced by the ratio of the area of the opening to the area of the room. The research results show that air temperature contours and air flow patterns can be a reference for determining thermal comfort in a room. Regarding the output of simulation, it is recommended that the energy savings calculations need to be carried out to find out how much impact the building's natural ventilation performance has on electrical energy use.

1. Introduction

Thermal comfort is a very important element of building design. Humans are said to be thermally comfortable when they cannot say whether they want the temperature to be hotter or colder in a room [1-3]. When indoor thermal conditions are uncomfortable, the atmosphere for indoor activities becomes unconducive. Thermal comfort can be controlled using a mechanical approach, mostly by using Air Conditioning (AC), but it requires quite a bit of operational costs. Some of the architectural

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https://doi.org/10.37934/arfmts.123.2.175183

approaches generally used are modifying the environment outside the building and the use of natural ventilation in the building [4-7].

Indoor thermal comfort can be controlled by improving the quality of ventilation. Improving the quality of ventilation can be done by designing air flows that are adapted to room air conditions [8-10]. In designing air flow, it is necessary to observe the thermal conditions of the room which can be done in various ways, one of which is simulation. Simulation modeling has advantages compared to direct measurement methods, since it produces more accurate analysis and building modeling results, and can optimize measurement time [11,12]. Simulation with software aims to visualize a model of a building based on actual conditions. The simulation approach begins with creating a building model that is as similar as possible to real conditions. The model can show interactions with various components so that it can describe the behavior of an environment that occurs [13,14].

This research uses SimScale software to simulate thermal comfort in a building. SimScale is cloud-based Computer Aided Engineering (CAE) software [15-18]. By being cloud-based, the software does not need to be downloaded and installed on a computer. The use of SimScale Software is a tool for simulating Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD), and Thermal Analysis. SimScale uses OPENFOAM as a toolbox to solve complex CFD problems. OPENFOAM provides impressive accuracy and is widely used in academic and industrial settings [19-22]. The toolbox is continuously developed and expanded by a large community of scientists and experts to ensure its rapid implementation of new technologies.

This study uses Faculty of Sports Science Building, State University of Malang, Indonesia. This is a 7-floor building with one basement. The shape of the building is rectangular with the building orientation extending along the west and east direction. Overall, the building elements use glass material on all sides which results in a fairly high heat intensity of solar radiation. The performance of natural ventilation is considered insufficient to overcome the thermal conditions in classrooms, so air conditioning (AC) is used. This research was conducted to determine the thermal comfort of classrooms in the Faculty of Sports Science Building, State University of Malang. Simulation modeling using SimScale software can be used to determine the level of thermal comfort in a room. The simulation modeling carried out is expected to produce variable output of air temperature and air flow pattern as contours which can be analyzed.

2. Methodology

In this research, the first step taken was to collect the required Detailed Engineering Design (DED) data for the classrooms of the building. The data included (1) openings design such as the dimension and the geometry of the windows and inlets or outlets of natural ventilation, (2) the length, width, and height of the rooms, (3) construction and materials of exterior and interior walls, (4) construction and materials of ceiling. Based on local climate data, such as average temperature and daily air temperature, the next step was to compile simulation input variables, creating a three-dimensional model of space design using Rhinoceros 4.0 software based on DED data in the form of plans, views, sections and details of building elements. Grouping climate condition data in the form of average and maximum air temperature values and average air flow velocity values was needed before simulation variables entry data. In simulating thermal condition, SimScale needs to create fluid simulations in the room of designated model (Figure 1). It is necessary to carry out a fluid volume modeling process in the model, which is called flow volume extraction.

After conducting the simulation, various output variables were obtained. The various output variables were obtained from simulation modeling with predetermined input variables. Descriptive techniques are used to explain the results of the simulation by processing and analyzing the data that has been obtained into systematic, orderly, structured, and meaningful data. Analysis of research data from simulation results in the form of air temperature contours and air flow patterns will show hotter or colder locations in the room. So that the extreme locations that are uncomfortable in the research object can be described.

The air temperature contour is an output variable from the simulation results. With the contour data, areas in the room that are less comfortable can be identified by analyzing the output variables descriptively. Descriptions related to the air temperature contour output variable can be the basis for carrying out thermal control so that uncomfortable areas in the room can be prevented. It can be concluded that the air temperature contour output variable can be the basis for assessing the level of thermal comfort in the room as well as being one of the references in designing the room.

The air flow pattern is an output variable from the simulation results. With the airflow pattern data, it can be known the air movement that occurs in the room by analyzing the output variables descriptively. Descriptions related to the airflow pattern output variables can be the basis for solving problems that occur so that air movement can be evenly distributed throughout the room. Air movement even in warm or humid conditions can cause heat loss through convection. So, it can be concluded that the airflow pattern output variable can be the basis for assessing the level of thermal comfort in a room and can also be a reference in designing a room.

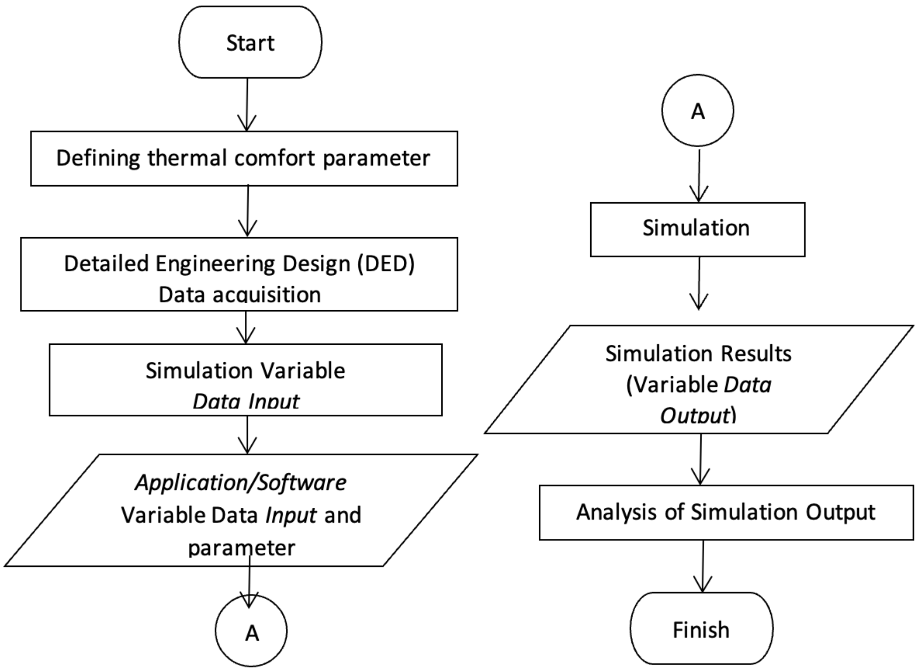

Fig. 1. Simulation process by using SimScale

3. Results

The rooms with openings that can circulate air in and out of the room are selected. Classrooms in the case study building have typical room size but varied for opening design. Grouping was carried out according to the area of the room (length, width and height) and the type of windows in the classroom. The type of classroom in the Faculty of Sports Science building is shown in Table 1.

Table 1
Classroom types

Type	Dimension (m)			Windows type
	Length	Width	Height	
A	8	8	4	J4
B	10,5	8	4	J4
C	12	8	4	J4
D	8	8	4	J4A
E	10,5	8	4	J4A
F	8	8	4	J4B
G	10,5	8	4	J4B
H	10,5	8	4	J5A
I	12	8	4	J4B, CW3, CW4A

The climate data used in this research is the average and maximum air temperature and average wind speed values. This data is gathered from current climate database available at Karangploso Post Climate Observatory Station and Abdul Rahman Saleh Air Base Post in Malang Regency. Table 2 shows the climate data used in this research.

Table 2
Climate condition

Month	Temperature (°C)		Average of air flow velocity (m/s)
	Average	Maximum	
January	24,1	29,0	0,81
February	23,9	29,2	0,56
March	23,7	28,9	0,61
April	24,1	29,2	0,61
May	23,7	29,1	0,78
June	22,3	28,0	0,92
July	21,7	27,7	0,92
August	22,0	28,1	1,17
September	23,1	29,9	1,22
October	25,1	31,9	1,28
November	25,4	31,4	4,67
December	25,0	30,6	3,67

Thermal comfort simulation modelling with SimScale software will produce variable output data for air temperature contours and air flow patterns in the classroom design model. The colour scale in the air temperature contour simulation results can show the air temperature value in degrees Celsius (°C). Figure 2 is an example of the simulation results for the air temperature contours of type D and E classrooms during the simulation in October. It shows that two types of classrooms have average temperature of 28.65°C and 26.65°C respectively.

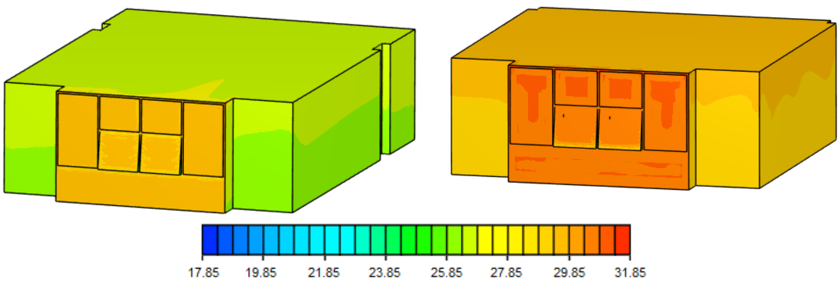

Fig. 2. Simulation results of air temperatures

The air flow velocity value can be determined by observing the colour scale in the air flow pattern simulation results. An example of the simulation results of type D and E classroom air flow patterns during the simulation time in December can be seen in Figure 3. It shows that the average air flow velocity in December are 0.11 m/s and 5.6 m/s respectively.

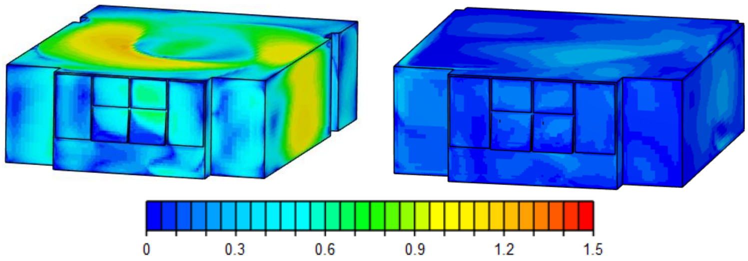

Fig. 3. Simulation results of air flow patterns

Based on the air temperature contour, the average air temperature value that occurs in the classroom can be known. An analysis was carried out by grouping the simulation results based on type and time (months), compared with applicable standards, and presented using graphs to obtain conclusions about the research results. Classrooms can be categorized as thermally comfortable or uncomfortable based on Indonesia's National Standard (SNI 03-6572-2001) regarding categories of comfortable temperature levels for Indonesians. Figure 4 is an example of a graph of air temperature values in a type A classroom to SNI.

Type A is a classroom that has a floor area of 8 m x 8 m with two J4 type windows. Based on Figure 4, the air temperature in type A classrooms from January to December is classified as a comfortable air temperature, or optimal comfortable and comfortably warm categories. The highest average air temperature occurs in February and April with a value of 26.55°C which is included in the comfortably warm category.

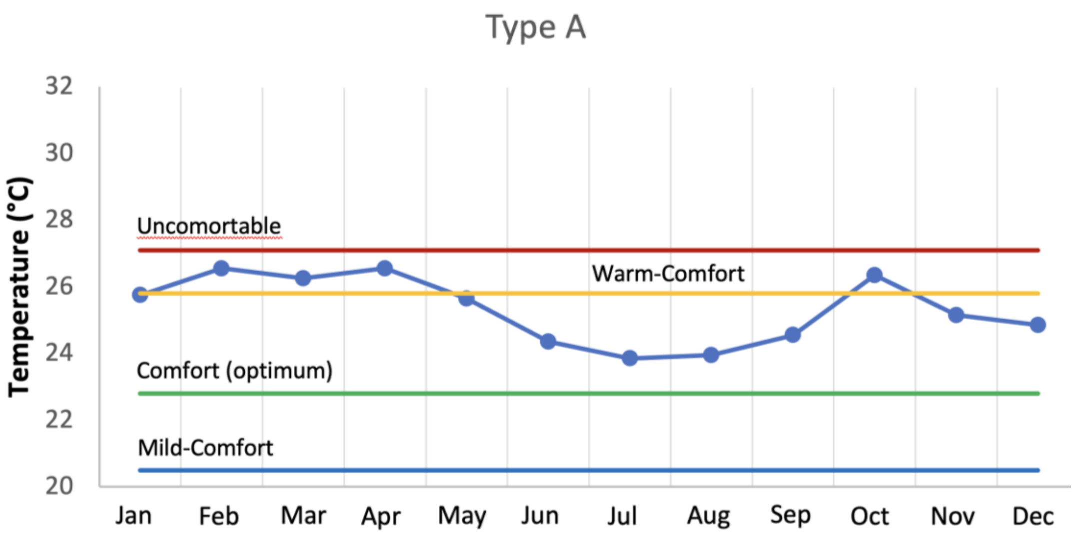

Fig. 4. Graph of type A classroom air temperature values

Based on the results, the area of a space will influence thermal comfort conditions. The wider the room will help in achieving comfortable conditions. The results of this research are in accordance with the simulation results obtained in type D and type E classrooms, both types have the same type and number of windows but type E has a larger room than type D classrooms. Likewise, the results obtained in classrooms type F and type G, the wider the classroom, the air temperature tends to be in a comfortable condition.

Type A and type D classrooms have the same floor area but with different types and numbers of openings. In type A classrooms, the simulation results obtained for air temperature values tend to be in comfortable conditions compared to the air temperature values that occurs in type D classrooms. Likewise, the differences in simulation results obtained in type A and type F classrooms. It shows that the ratio of floor area to opening area can influence the cooling temperature in the room.

Based on the air flow pattern, the average velocity value that occurs in the classroom can be determined. An analysis was carried out by grouping the simulation results based on type and time (months), compared with applicable standards, and presented using graphs to obtain conclusions about the research results. Classrooms can be categorized as thermally comfortable or less comfortable based on SNI 03-6572-2001 concerning wind speed for comfortable conditions regarding the prevailing air temperature as well as the average subjective reaction to wind speed. Figure 5 is an example of a graph of wind speed values in a type A classroom and the average subjective reaction to air flow velocity.

Type A is a classroom that has a floor area of 8m x 8m with two J4 type windows. Based on Figure 5, the air flow velocity that occurs in type A classrooms from January to May is below SNI, while in September, November and December the value is above SNI. In June, July, August and October is approximately the same as the SNI recommended air flow velocity for comfortable conditions. The velocity that occurs from January to October is less than 0.25 m/s and classified as still air. In November the air flow velocity that occurs is included in the disturbing category, while those in December is categorized as breezing wind.

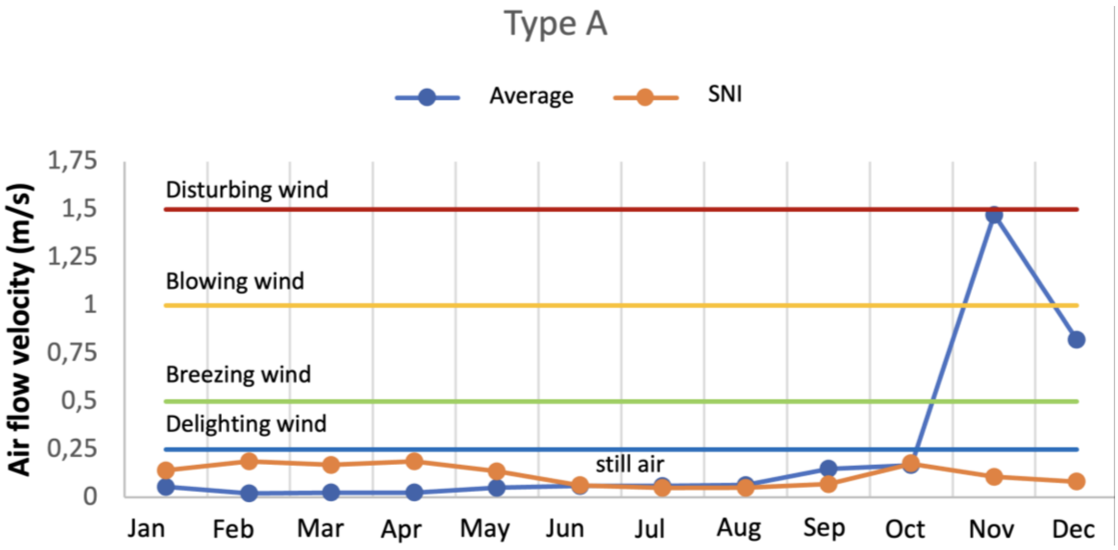

Fig. 5. Graph of Wind Speed Values for Type A Classrooms

From all types of classrooms, the simulation results show that air flow velocity values tend to be low and are classified as still air (<0.25 m/s). This low velocity of air flow in the classrooms since in each type of classroom there are no openings facing each other that leads to poor air circulation.

Type A and type D classrooms have the same floor area but the openings in type A classrooms are wider than the openings in type D classrooms. In type A classrooms, the simulation results show that air flow velocity values tend to be greater than the prevailing values in type D classrooms. Likewise, the differences in simulation results obtained in type A and type F classrooms. Air circulation is influenced by the ratio of the opening area to the room area. The simulation results showed that type A classrooms which have a larger opening area have higher air flow velocity compared to type D and type F classrooms.

Air temperature and air flow velocity are two interrelated factors in determining thermal comfort conditions. When the air temperature in a room is in the comfortable category, according to SNI 03-6572-2001, the recommended air flow is to be maintained at no greater than 0.25 m/s and it is better if it is less than 0.15 m/s. The subjective reaction to air flow velocity can be used as a reference to determine whether its velocity that in a room is considered acceptable or disturbing. Table 3 explains the comfort in each type of classroom from January to December based on air temperature and air flow velocity values compared to SNI 03-6572-2001 and subjective reactions to wind speed.

Table 3
Thermal comfort condition of each room type

	A	B	C	D	E	F	G	H	I
January	O	O	X	O	O	O	O	O	X
February	O	O	X	O	X	O	O	O	X
March	O	O	X	O	O	O	O	O	X
April	O	O	X	X	O	X	O	O	X
May	O	O	X	O	O	O	O	O	X
June	O	O	X	O	O	O	O	O	O
July	O	O	O	O	O	O	O	O	O
August	O	O	X	O	O	O	O	O	O
September	O	O	X	O	O	O	O	O	X
October	O	X	X	X	O	X	O	X	X
November	O	X	X	O	O	O	O	O	X
December	O	O	X	O	O	O	O	O	X

Remarks: O = comfortable; X = uncomfortable

4. Conclusions

The simulation results of air temperature contours and air flow patterns as the output variables from the SimScale can be used to measure indoor thermal comfort. SimScale can make it easier for planners to design room design by observing aspects of thermal comfort. Based on the air temperature contour, the thermal comfort of a room can be influenced by room area and the ratio of opening area to floor area. Based on air flow patterns, the thermal comfort of a room can be influenced by the position of the opening and the area of the opening relative to the area of the room.

Air temperature and velocity are two interrelated factors in determining thermal comfort conditions. When the air temperature in a room is categorized as comfortable, according to SNI 03-6572-2001, the air flow velocity is recommended to maintain the comfortable condition, which is not more than 0.25 m/s and better if the value is less than 0.15 m/s. However, if the air temperature in the room is categorized as uncomfortable, then the air flow velocity can be a balancer to overcome the air temperature so that comfortable conditions will be obtained in a room.

Acknowledgement
The study as written in this paper was conducted by full support of funding provided by the Institute of Research and Community Services, Universitas Negeri Malang, Indonesia.

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