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The adaptive thermal comfort of individual performance working at home

Jocelyn Octavia Ongkowiyono[1], Geby Nathasha Tiffany Budianto[1], Elizabeth Ferren Armelia[1], Vio Angelina Ongkowiyono[2], Christina Eviutami Mediastika[1*]

[1] *Architecture Study Program, Universitas Ciputra Surabaya, Indonesia*
[2] *Psychology Study Program, Universitas Ciputra Surabaya, Indonesia*

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***Corresponding author**: Christina Eviutami Mediastika
Architecture Study Program, Universitas Ciputra Surabaya, Indonesia
Email: eviutami@ciputra.ac.id
ORCID: https://orcid.org/0000-0002-9049-4897

ABSTRACT

Eco-friendly architecture (EFA) is a design approach to produce healthy and comfortable buildings. In the pandemic era and in years to come when working from home is a trend, a healthy and comfortable home is crucial because people spend their time at home. Thermal comfort is considered the most significant comfort factor for building occupants, especially at home. This paper reports a study on the relationship between thermal comfort, individual performance, and productivity while working at home. Data was collected qualitatively through observation, heat transfer calculation, and in-depth interviews. This study concludes that a thermally comfortable house that follows the EFA concept is an aspect that influences performance and productivity. However, thermal comfort is not the only aspect related to comfort. Habits and adaptation of occupants to certain conditions also affect comfort, which leads to good performance and productivity. Occupants feel comfortable doing office and household tasks at home due to their adaptation to the surrounding thermal comfort based on their preferences.

Introduction

The main goal of building design is to provide comfort to the users. Moreover, it is not only comfort but also health. Health and comfort are two different things, but they can be directly or indirectly interconnected. A building that ensures the health of the occupants should also ensure comfort, even it is not always the case. For example, a building that was designed for direct sunlight to enter its rooms for germs killing (Kesavan and Sagripanti 2013; Zuhri, Firdauzy, and Ghozali 2020), may provide uncomfortable indoor temperature since direct sunlight increases indoor temperatures. Meanwhile, a comfortable room in term of its coolness may not necessarily healthy because cool temperature without direct sunlight may increase humidity level for the spread of germs (Purnamasari, Suharno and Selviana 2017; Wen et al. 2020). Therefore, both the health and comfort of building inhabitants should become two things to be taken into account by building planners or architects (Santos et al. 2017; Fairuza, Riska, and Kusuma 2021).

It is crucial for a building to pay attention on health and comfort, in particular, when it is a house, since human spends most of their time at home. The indoor period at home even more significant during the COVID-19 pandemic (Lips, 2021; Hulls et al. 2022; Duran and Ömeroğlu 2022; Restrepo and Zeballos 2022). Even if it is easy to spot that in this modern era, people spend one third up to half of their time outside their house, but some studies state that, still, people spend more of their time in the house or their surroundings (Masrur 2021; Faulds and Raju 2021). Besides the importance of health and comfort issues for inhabitants, a building should ideally ensure its harmony with its surroundings. Buildings shall spare open space for rainwater absorption and permitting daylight from its walls for energy savings (Seyam 2019; Gupta and Chakraborty 2021; Dutta 2023).

All efforts to bring buildings to minimize the negative effects to the environments, including efforts to provide health and comfort to the inhabitants, is an eco-friendly architecture (EFA) design approach. The EFA concept refers to various planning and design elements, including city planning, urban planning, interior and exterior spaces, and building structures considering natural physical conditions, including water, soil, air, climates, light, sounds, and humidity. One of EFA's concepts that is plausible to minimize the negative effects of buildings on the environment is by paying attention to the use of building materials and energy. Related to energy, architects have to rethink that climate plays crucial roles on inhabitants' comfort of a building (Sung, and Hsiao 2020; Utomo, Fananiar, and Pangesti 2021). So, it can be concluded that an eco-friendly building has to carefully consider the climate where the building is located as it will affect the use of energy.

Furthermore, indoor comfort affects inhabitants' working performance including productivity, even when it is about the working performance inside a house. Hakim (2006) and Ganesh et al. (2021) mention there are many factors affect indoor comfort, but the most important is thermal factor. There are many studies have been carried out to investigate the relation between thermal factors with inhabitants' performance, such as thermal comfort in classrooms (de Dear et al. 2015; Kartika and Iswanto 2020), in workshops (Prasetyo 2012) in offices (Indraganti, Ooka, and Rijal 2013 and 2015), as well as in mosques (Noman, Kamsah, and Kamar 2016; Atmaca and Gedik 2019; Rahmananda et al. 2021). However, there is relatively limited study about comfort and working performance or productivity at home, which could have been more attractive as in the future there is a trend for people to work from home. This study uses the EFA concepts to determine the influence of inhabitants' comfort on individual performance or productivity while working at home in two different location that is Surabaya and Tangerang. The study's novelty lies in using quantitative (field measurement and calculation) and qualitative aspects (closed and open questionnaires) and their effect on individual working performance or productivity. Earlier studies used only quantitative aspects to answer the question (measurements and Likert scale questionnaire) of inhabitants' adaptability and did not investigate adaptive thermal comfort and working performance such as those by Feriadi and Wong (2004) and Jiao et al. (2020).

Methods

This research used quantitative and qualitative approaches, using two case studies of residential houses in Surabaya and Tangerang. The two houses were selected based on the different latitudes, but both were located in warm, uncomfortable cities (Hogianto and Mediastika 2019; Putra et al. 2023). Surabaya is on 7.2458° S and Tangerang is on 6° 10′ 17″ S latitute. Earlier studies indicated that latitude affects outdoor and indoor thermal comfort strategies (Zhang et al. 2022; Zhang et al. 2023). The data collected were the aspects of residential thermal explored through observation and heat transfer calculation. The observation was completed using an open questionnaire filled out by the house inhabitants to explore their perceptions of comfort and performance. Literature studies and documentation support the observation to conduct the analyses.

Results and discussion

This research used two objects of study located in Surabaya (next, it is namely house 1) and the district of Tangerang (next, it is namely house 2) (figures 1-3). While house 1 functions solely as a residence, house 2 functions as a residence and office because one is an entrepreneur. The two houses are similar in that both are facing eastward, located on a plot of land extending to the rear, and have two floors. Besides the three similarities, the two differ architecturally, among which is that the front facade of house 1 is more extensive, while house 2 is more extensive in its side facade. The two also have differences in their surrounding environments and opening placement. Besides the above differences, tables

1 and 2 explain other differences more specific to the conditions of the two houses.

Figure 1. Facades of house 1 (left) and house 2 (right)

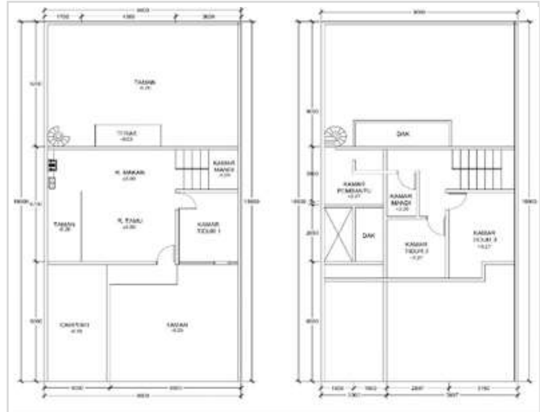

Figure 2. Floor plan of house 1 (ground and 1st floors)

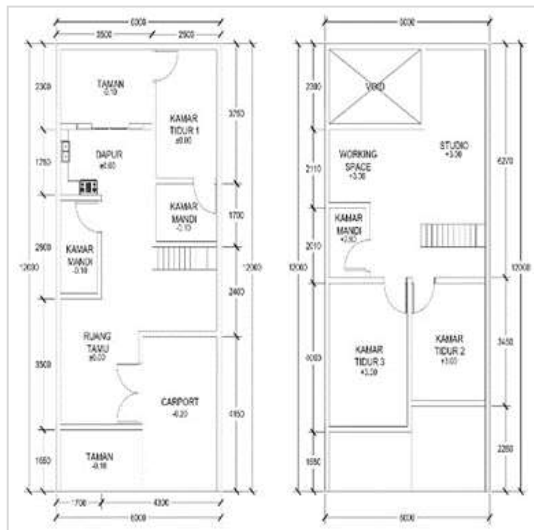

Figure 3. Floor plan of house 2 (ground and 1st floors)

To investigate the heat transfer at the objects researched, heat was calculated in radiation, conduction, and convection modes and then completed with internal heat gain calculation. The use of building materials available in the two objects causes different values of heat transfer. Radiative transfer was calculated using the equation, as follows:

Qs transparent = G x A x sgf ....(1)

Qs opaque = Σ(AxU)(GxabsxRso)................(2)

In which Qs stands for solar heat gain (Watt), G is wall radiation (W/m^2), A is the area (m^2), sgf is glass solar gain factor, Rso is resistence surface outdoor, U is material U-Value (W/m².ºK), and abs is absorption (L mol-1 cm-1).

Radiation heat transfer occurs in the two objects through glass windows and through the roofs. However, because the roof of house 2 is wider than the roof of house 1, the radiative heat transfer in house 2 occurs more. Then, the conductive heat transfer was calculated using the following equation:

$Qc = \Sigma(AxU) \times dT$..(3)

In which Qc stands for conductive heat gain (Watt), A for area width (m^2), U for material U-Value ($W/m^2.^oK$), and dT for time difference (s).

Table 1. Conditions and thermal strategies

	House 1	House 2
Rainfall	4%	43%
Tempe-rature	23°C - 36°C	23°C-32°C
Humidity	77%	64%
Wind velocity	13 m/s	2,8 m/s
Resi-dents' strategies toward thermal conditi-ons	Like using air conditioners, the windows and doors are never opened for air cha-nge, and there are no other ventilation features.	Only use air conditioners sometimes; the windows and doors are regularly opened for air change, and there are no other ventilation features.

While convective heat transfer is calculated using the following equation:

$Qv = 0,33 \times N \times A \times dT$...............................(4)

In which N stands for air changes per hour (times/hour), A for area width (m^2), and dT for time difference (s).

Convective heat transfer in the two objects occurs in all areas inside the house because all inner spaces are connected by internal doors that are always open. The two objects also have a void (open center room from the first to the second floor). Next, internal heat gain was calculated using the following equation.

Qi = (number of persons x duration of activi-ties x metabolic rate) + (lights x duration)...(5)

In which duration of activities is in hours, metabolic rate is in kkal, and lights is in Watt.

Table 2. Data of residents

	House 1	House 2
Loca-tion	Surabaya City	Tangerang District
Resid-ents	3 females (ages:18,42, 45) and 2 males (ages: 21, 22)	1 female (age 30) and 1 male (age 29)
Des-cripti-on	Based on the physical resident conditions, 3 females are categorized as overweight since the body mass indices are in the range of 25-30 kgs/m^2, while 2 males are classified as healthy weight since the body mass indices are in the range of 18.5-25 kgs/m^2. Four residents are employees, and 1 female is an undergraduate student. The five residents feel good and comfort to stay in cold air. They get used in using air conditioners (AC).	Physical resident conditions: the female resident is categorized as overweight because the body mass index is 25-30 kgs/m^2; the male resident is classified as healthy weight since the body mass index is in the range of 18.5-25 kgs/m^2. The female resident is a housewife, and the male resident is an employee and an entrepreneur seeking additional income. The female resident cannot stand cold air, so she is not used to using AC, while the male resident has no problem with the cold air and likes to use AC.

Based on the above calculation, heat transfers through materials are obtained as shown by tables 3 to 5.

Table 3. Radiative heat transfers

	House 1 (Watt)	House 2 (Watt)
West walls	13.254,70	-
East walls	4.293,22	19.005
West glasses	7.010,78	-
East glasses	15.022,39	46.025
West roofs	6.268,97	31.528
East roofs	6.396,40	32.168

Table 4. Conductive heat transfers

	House 1 (Watt)	House 2 (Watt)
Walls	569,38	637,50
Glasses	154,30	729,20
Roofs	615,60	765,00

	House 1 (Watt)	House 2 (Watt)
Woods	62,10	-

Table 5. Convective heat transfers

House 1		House 2	
Rooms	**Qv (Watt)**	**Rooms**	**Qv (Watt)**
Kitchen	165.33	Kitchen	283.47
Bedroom 1	46.78	Bedroom 1	14.85
Living room	67.83	Sitting room	47.5
Dining room	43.60	Bathroom 1	101.9
Bathroom 1	90.21	Bathroom, 2	103.9
Bedroom 2	43.44	Bedroom 2	269.80
Bedroom 3	53.46	Bedroom 3	326.7
Bathroom 2	94.22	Bathroom 3	76.23
Maid's room	22.72	Studio	48.5
Qv total	627.59	**Qv total**	1272.48

Based on the results of heat calculation in tables 3 to 5, we learn that house 2 receives more heat than house 1. It happens because of the difference in location, in which house 2 is in Tangerang, with the average daily temperature tending to be higher than that in Surabaya (table 2); it is also because house 2 tends to be routinely opened to welcome outer air into the building. The thermal strategy of opening the doors, windows, and other ventilation features is less supported if the wind velocity around the building is low, as in the case of house 2. The wind velocity happening in the objects due to the use of openings is shown in table 7. It is seen that wind velocity in house 2 is insufficient to expel the heat in the house. In house 1, the wind velocity is calculated as 0 because the opening in the house is never left open.

Meanwhile, by calculating internal heat gain or the heat circulating in the rooms (table 6), it is evident that house 2 generally has more heat than house 1. It strengthens the former findings related to radiative, conductive, and convective heat transfer, showing that house 2 is hotter.

Table 6. Internal heat gain

House 1		House 2	
Rooms	**Qi (Watt)**	**Rooms**	**Qi (Watt)**
Bedroom 1	1.360	Bedroom 1	-
Bedroom 2	1.360	Bedroom 2	-
Bedroom 3	800	Bedroom 3	1.360
Kitchen	1.560	Living room	1.690
Dining room	655	Kitchen	720
Maid's room	1.360	Studio	1.860

Table 7. Wind velocity (m/s)

	House 1	House 2
1st floor	0 m/s	0.65 m/s
2nd floor	0 m/s	0.92 m/s

Based on thermal calculations, it is evident that house 2 is less comfortable (because the heat in the house is higher) (Ganesh et al. 2021). However, the residents of house 2 feel comfortable. Since the two groups of residents felt comfortable, one regularly uses AC, and the other only uses AC occasionally, the authors decided to interview them using a structurally prepared list of questions. The interview was conducted to confirm perceived comfort and productivity while working in a particular indoor environment. The interview results are presented in figure 4.

The responses show that residents of both houses are more productive when they feel comfortable. Within a comfortable environment, they are encouraged to finish their task faster and even try and do new activities they have never done before.

Besides the structured questions, at the end of the interview, residents are also requested to describe their perception of comfort and productivity in sentences. The inhabitants of house 1 narrated their perceptions as follows:

"My working performance would improve in a comfortable environment, and I would become more productive."

"As long as I am comfortable, I work more comfortably as well. I would be more pleased if I didn't have to sweat when it is not hot. Working and having meetings at home would be comfortable without nuisance when it is not noisy."

"I felt delighted because a comfortable house would improve my physical and mental conditions."

"In a comfortable working environment, I feel less tired and more satisfied with my work results."

"My work at home is fine because I enjoy working and doing things at home."

Meanwhile, the residents of house 2 perceived comfort and performance as follows.

"A calm atmosphere would make me focus on doing something. When the house is comfortable, we can be inspired to innovate in many things".

"Certainly, the results were maximum when we worked in a comfortable atmosphere. We would become more productive and peaceful in doing things."

The answers to the open question prove that indoor thermal comfort is essential for people doing their work and other activities at home (Ganesh et al. 2021). It is not rigid but adaptive instead (Feriadi and Wong 2004, Indraganti, Ooka, and Rijal 2013 and 2015; de Dear et al. 2015; Jiao et al. 2020). Once inhabitants feel comfortable, their performances are at their best.

Conclusions

Studies on thermal comfort and individual performance at home concerning productivity (particularly during the pandemic) have been carried out on two houses in Surabaya and Tangerang. Thermally, the house in Tangerang receives more heat in the rooms, which decreases the comfort level; however, the atmosphere in house 2 is deemed comfortable enough by the residents who are not used to using AC and tend to feel uncomfortable in cold temperatures. Meanwhile, the residents of house 1 are dependent on AC because they are used to believing that AC brings comfort. Based on this finding, we learn that the comfort level of a house depends very much on the habit and adaptability of the residents to their respective houses. Even if, theoretically, it is less comfortable, since the residents have adapted to and found their comfort, the thermal element is not the main issue. In general, in the thermal comfort of the two houses, the residents of both houses felt comfortable in their personalized ways, could work well, and did their tasks responsibly.

A further conclusion is drawn that a comfortable house following the concepts of EFA is essential to support good performance and productivity. However, this study indicated that thermal comfort is not a rigid standard but also depends on the habits and adaptations of the inhabitants. Based on EFA, AC is to be avoided, but it can still be used wisely in such conditions where AC is needed. A study is required to seek the possibility of using continuous and constant AC 24/7 more effectively based on microenvironment management around the house or the building.

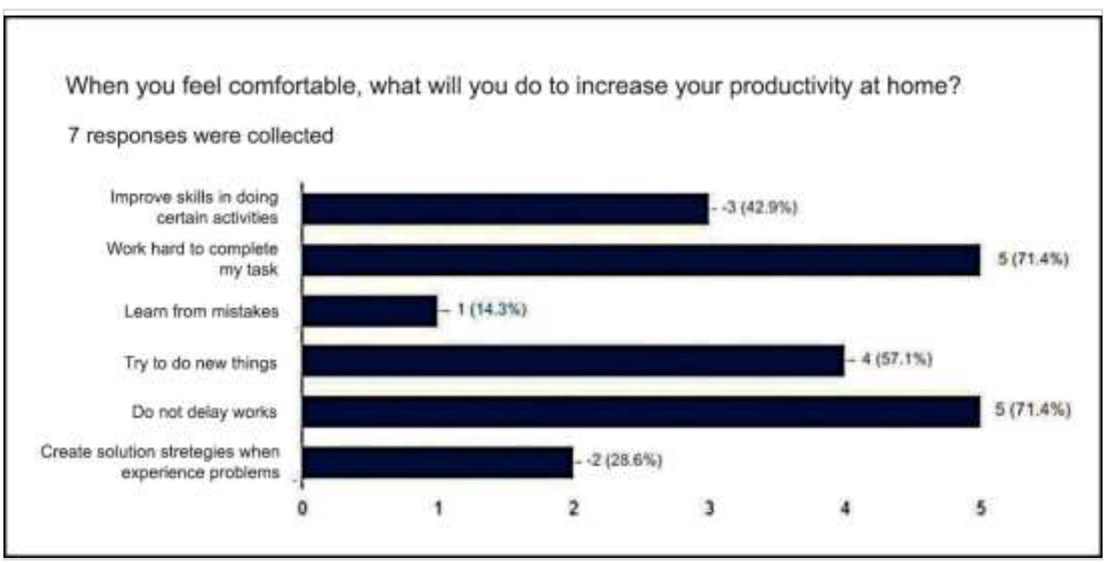

Figure 4. Responses related to comfort and productivity

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Author(s) contribution

Jocelyn Octavia Ongkowiyono contributed to the research concepts preparation, methodologies, investigations, data analysis, visualization, articles drafting and revisions.

Geby Nathasha Tiffany Budianto contribute to methodology, supervision, and validation.

Elizabeth Ferren Armelia contribute to methodology, supervision, and validation.

Vio Angelina Ongkowiyono contribute to methodology, supervision, and validation.

Christina Eviutami Mediastika contribute to the research concepts preparation and literature reviews, data analysis, of article drafts preparation and validation.