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Evaporative cooling strategy using cooling pad material made from stove wicks in walk-up flat in the humid tropical climate of Surabaya

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Abstract - Generally, the thermal conditions in simple flats for rent are still not within a comfortable range. There is no implementation of artificial ventilation (Air Conditioner) with adjustable air temperature, so passive strategies still need to be pursued. In this case, the strategy pursued is Direct Evaporative Cooling (DEC) system with cooling pads made from stove wicks. Experimental methods were conducted in one of the apartment buildings in Surabaya, namely Indrapura Walk-up Flat. The research results indicate that at relatively high outdoor air temperatures from 12:00 to 15:00 local time, ranging from 27.9 to 32^{o}C, the implementation of DEC was able to reduce the air temperature by 1.94-2.08^{o}C.

Keywords: cooling pad, direct evaporative cooling, stove wick, walk-up flat

1 Introduction

There are many passive cooling strategies that can be applied to achieve comfort in a building, such as solar shading, insulation, induced ventilation techniques, radiative cooling, evaporative cooling, and earth coupling [1]. One of them is the evaporative cooling strategy. This strategy is frequently employed in hot dry climates due its effectiveness in reducing air temperatures and elevating air humidity levels. Consequently, this approach indirectly contributes to the restoration of thermal comfort within a building by diminishing heat levels within the space and mitigating the dryness of the air.

Ideally, tropical climates are very appropriate to apply natural ventilation strategies. This relates to a tropical climate that has high air temperature and humidity. The application of natural ventilation is able to drain hot air in the room to the outdoors and replace it with cool outdoor air. However, in addition to the application of natural ventilation, DEC can be applied to tropical climates as an alternative to cooling spaces [2, 3].

Various studies have been conducted using evaporative cooling strategies in tropical climates. Physical model development has been undertaken to lower room temperatures and achieve thermal comfort [2]. The research focuses on evaluating various types of cotton-based cooling pads. On building facades [4], room walls [5], passive airflow through the application of physical models can determine the performance of evaporative cooling inside the space [6]. The research indicates that

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evaporative cooling strategies can reduce heat inside the room, but there is an increase in humidity levels [7].

Previous researchers have conducted studies on DEC, examining its performance and ways to enhance its integration [8]. Some researchers have also focused on the materials, area, and thickness of evaporative cooling pads, as well as analyzing air temperature, air velocity, and water volume in cooling pad [7, 9, 10]. This research delves into the performance of DEC in a building in a tropical climate, specifically in Surabaya, Indonesia. Surabaya has not yet met thermal comfort standards because its climate is characterized by high air temperatures and relatively high humidity [11]. Previous researchers have explained that Indonesia has an average annual temperature of 26-27°C and a daily average temperature of 34°C with a relative humidity of 70-90%, and air velocity ranging from 0.1-0.25 m/s. In Surabaya, the daily average temperature reaches a maximum of 36.4°C with 85% humidity. However, some types of buildings in tropical climates also exhibit neutral temperatures ranging from 26.1 to 29.8°C [12].

One way to restore thermal comfort in a building is by implementing passive evaporative cooling (DEC). Various studies have been conducted on low-rise residential units, analyzing the impact of different fabric cooling pads on the thermal conditions inside the rooms [13]. The materials used for cooling pads vary, including cotton fabric and stove wick. However, stove wick material is chosen due to its excellent absorption properties [14, 15]. Walk-up flat are chosen as the research object because DEC research strategies can be efficiently applied, and they are affordable [13, 16, 17]. This is suitable for the residents of walk-up flat, who are considered low-income, as an easily applicable solution is needed to address thermal comfort.

2 Materials and methods

This research aims to analyze the performance of evaporative cooling directly through a stove wick material cooling pad. The applied research method is experimental, involving direct field measurements to analyze the impact of direct evaporative cooling with a cooling pad on air temperature, humidity, and air velocity within the space. The study employs a DEC method that aligns with conventional DEC previously implemented [18], as illustrated in Figure 1.

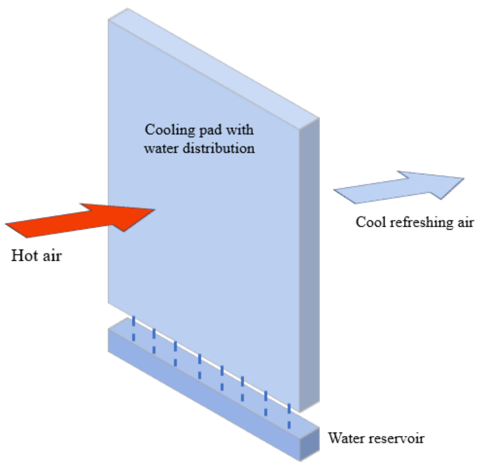


Fig 1. Cooling pad mechanism

The research was conducted in March - June 2022 starting from the preparation stage to direct measurements in the field. The first preparatory stage is the collection of annual climate data from the Juanda Meteorological Station as macroclimate data. The second preparation stage is to make a cooling pad with stove wick material. The next stage is data collection before the application of the cooling pad to find out indoor unit thermal environmental conditions data on walk-up flat from 9.00 am – 7.00 pm for 5 days. This aims to find out the right time when using a cooling pad. The last stage is measurement when using a cooling pad in the room unit. The cooling pad test was carried out for 5 days by spraying 450 ml of water every one hour to avoid excessive spilling water. The data collection for both without cooling and using a cooling pad was conducted on different days. However, the weather conditions during the measurements were under clear skies, and it was not cloudy.

The dependent variables are air temperature, air humidity, and air velocity. The independent variable in this study is the cooling pad material used, namely the stove wick (Figure 2). The research instruments are Manual Hot Wire Anemometer, Digital Hot Wire Anemometer, and Wet Bulb Globe Temperature. The control variables in this study were the amount of water and the area of openings in ventilation holes measuring 90 cm x 90 cm with top hung opening types. The amount of water that wets the cooling pad is 0.1 - 0.45 liters which supports evaporation for 0.3 - 1 hour.

Fig 2. Cooling pad

The 5-storey Indrapura walk-up flat is a typical building under development in Surabaya [16] so that this walk-up flat was chosen as the object of research (Figure 3). The selection of space units on the 2nd floor of the west is used as the object of research because in that section it is more exposed to solar heat according to thermal design.

3 Results and discussion

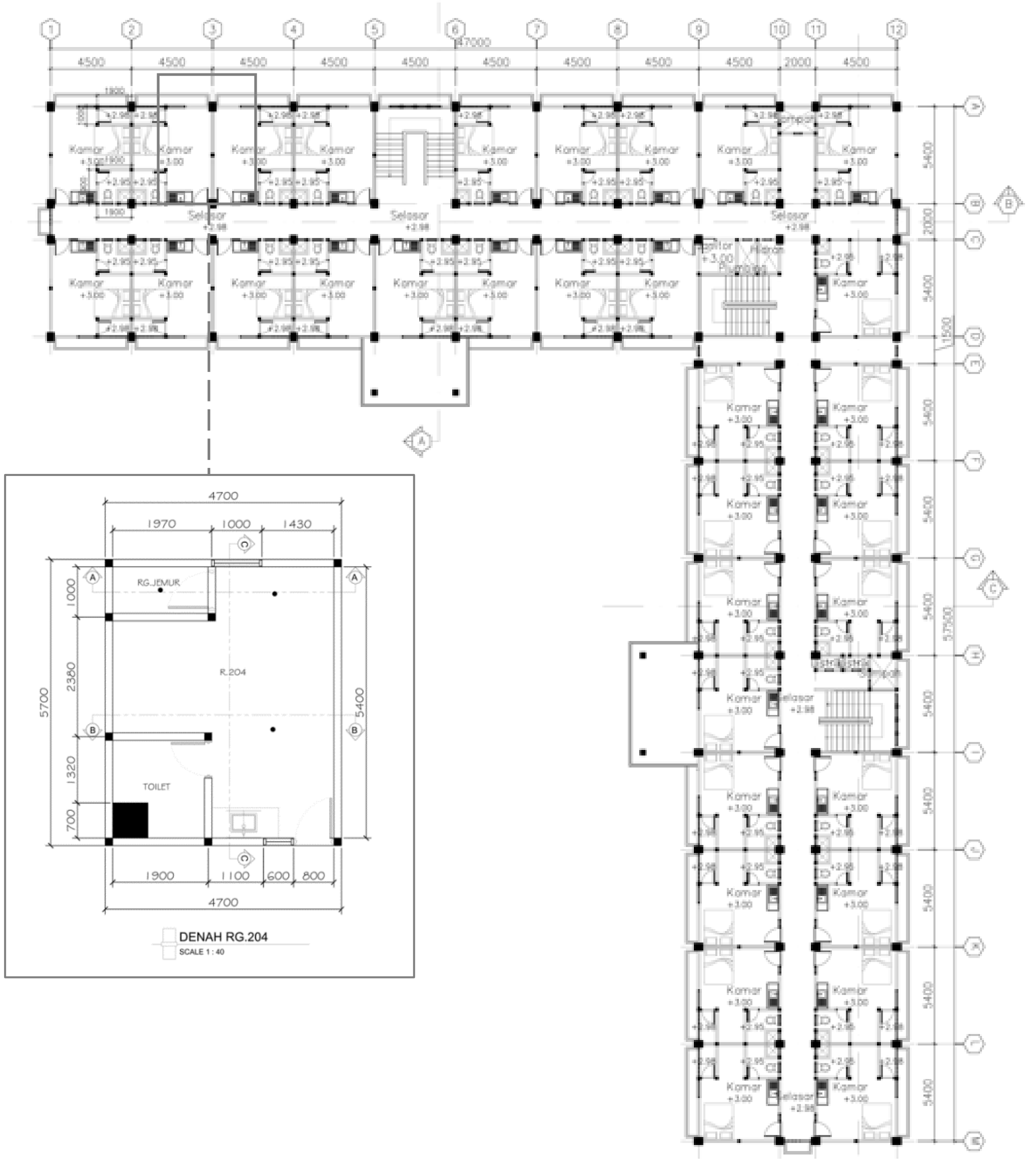
This research was conducted in 2 stages, namely the first stage without using a cooling pad and when using a cooling pad. In the first stage, researchers focused on direct observations in the field to obtain macro and indoor unit thermal environmental conditions data. Then the second stage, researchers conducted experiments on cooling pads with stove wick material.

3.1 Field observations

The results of field observations were carried out to obtain macroclimate data from Juanda Meteorological Station and indoor unit thermal environmental conditions.

3.1.1 Macroclimate data

Analysis of macroclimate data in this study was used to determine the thermal conditions and natural air conditioning that occurred in the city of Surabaya. The required data is annual climate data in a period of 5 years. This aims to determine air temperature, air humidity, and air velocity. Annual climate data is obtained from Juanda Meteorological Station from 2017 – 2021.



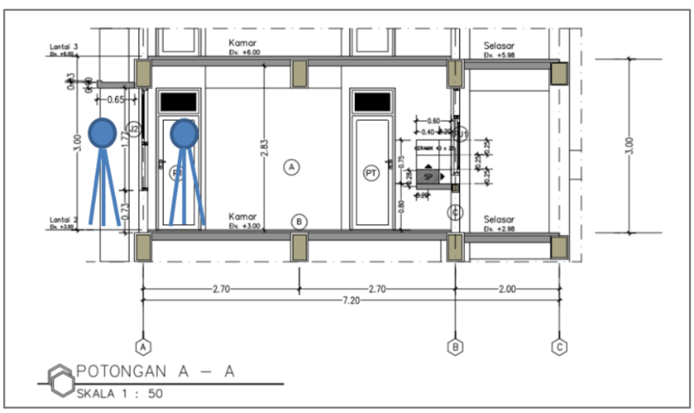


Fig 3. 2nd Floor Plan of Indrapura Walk-up Flat and Experimental Living Unit

Table 1. Average Macroclimate Conditions of Research Location in 2017-2021

Year	Air temperature (ºC)	Air humidity (%)	Air velocity (m/s)
2017	28.0	68.8	4
2018	28.1	76	3
2019	28.0	68.8	3.8
2020	28.3	79.1	2.7
2021	28.0	79.3	5.0

Table 1 shows the average value of air temperature, air humidity, and air speed from 2017-2021 obtained from Juanda Meteorological Station. The average air temperature in the last 5 years was the highest in 2020 at 28.3ºC. However, from year to year the air temperature according to Juanda Meteorological Station ranges from 28 ºC.

The air humidity of the last 5 years is presented in table 1. The highest air humidity in 2021 was 79.3% and the lowest in 2017 and 2019 was 68.8%. There is a change from 2019 to 2020, the air humidity is getting higher.In 2021, the air velocity was very high at 5 m/s and the lowest in 2020 at 2.7 m/s. The increase in air velocity seen in 2020 to 2021 reached 2.7 m/s.

Based on the data in the table shows that in Indonesia, precisely in the city of Surabaya, it has an annual average temperature of 28ºC with a relative humidity of 68-79%. This indicates high air temperature and humidity [12, 19].

3.1.2 Indoor Unit Thermal Environmental Conditions

This data was used to analyze indoor unit thermal environmental conditions in Indrapura Walk-up Flat with the aim of obtaining the right time in using the cooling pad. The thermal conditions measured are air temperature, air humidity, and air velocity at 9.00 am – 7 pm.

Figure 4 that the highest outdoor air temperature (To) at 1.00 pm is 34ºC. However, the indoor air temperature (Ti) was 33.7ºC in a room with a western orientation. Starting from 12.00-15.00 WIB the air temperature is higher than in other hours by 32.1-33ºC. The air temperature that can be accepted by indoor residents in tropical climates ranges from 26.1ºC – 28.9 ºC (Sabarinah). It can be said that outdoors and indoors are not in the comfort zone at 9.00 am – 4.30 pm. This shows that at these hours the air temperature condition is an uncomfortable condition felt by residents when outside or indoors.

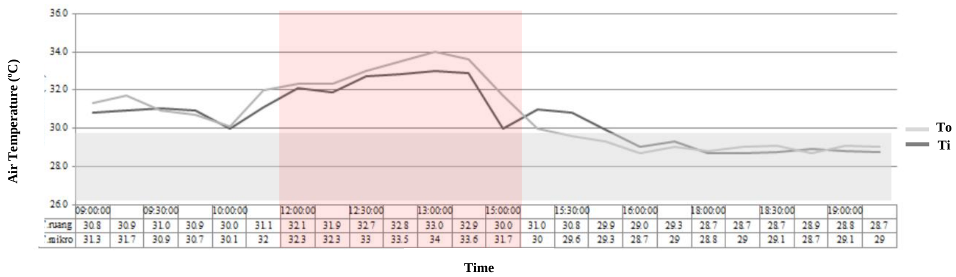


Fig 4. Air temperature without cooling pad

Contrary to air temperature, the higher the air temperature, the lower the air humidity in the room. Seen in the picture shows the air humidity outside the room and inside the research room in the western orientation is relatively high ranging from 65-75% [19]. The highest humidity occurs at 3.00-7.00 pm of 73.8-75.6% followed by a decrease in air temperature. However, at 12.00 - 3.00 pm the air humidity shows a smaller number than in other hours, which ranges from 63-73.8% (Figure 5).

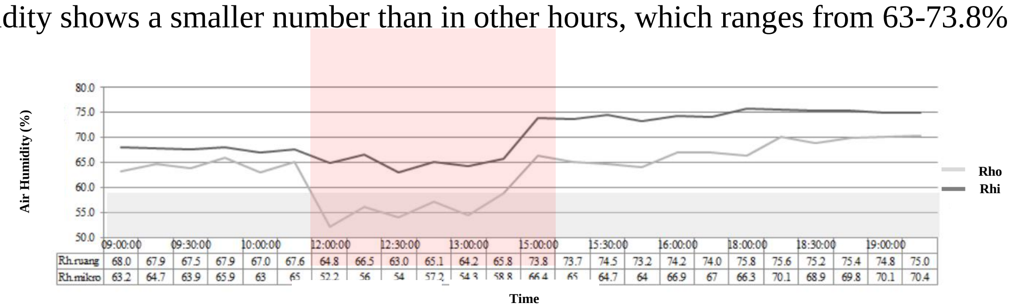


Fig 5. Air humidity without cooling pad

Figure 6 shows that the air velocity around the building ranges from 0.7 - 1.7 m/s. This condition shows that the air blows from the west and at 12.00 – 4.00 pm is the time with the most wind compared to other times. When associated with the comfort zone of air velocity which is in the range of 0.1 - 0.5 m/s, then at 3.00 - 7.00 pm is a comfortable time to feel the air velocity but at 12.00 - 3.00 pm the air velocity is relatively fast.

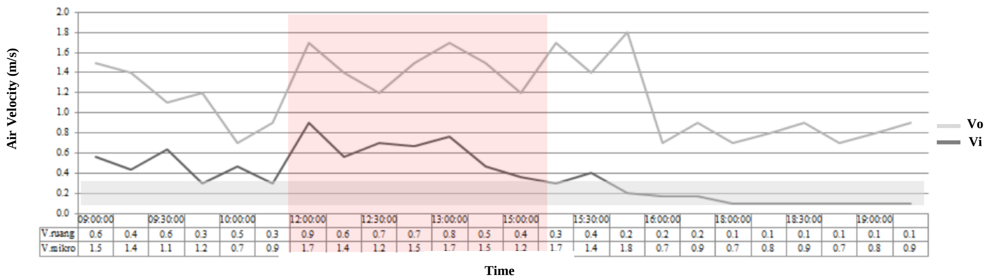


Fig 6. Air velocity without cooling pad

Based on the description above, it can be concluded that at 12.00-3.00 pm is the right time to apply the cooling pad. This is evidenced by the high air temperature at that hour followed by lower air humidity compared to other times and the amount of air that enters space compared to other times.

a) *Experimental results*

The experimental results on the application of an evaporative cooling system directly with stove wick material are shown on the graph of air temperature, air humidity, and air velocity.

Figure 7 shows a decrease in temperature ranging from 1.2 – 1.9 per hour. At 3.00 pm. It was the highest decrease of 1.94 from the outdoor air temperature of 29.9°C to 27.9°C. However, it can be seen at 3.00 pm that it has entered the air temperature comfort standard, which is 27.9°C. Based on previous research, the use of stove wick material has an impact on lowering air temperatures by 0.2-1.5°C. Similarly, in this study, it was able to reduce air temperatures by 1.2-1.9°C. When compared to cotton-based cooling, which can lower the air temperature by 1°C, stove wick material performs better [15]. This is related to the higher the area and the thicker the cooling pad, the greater the tendency of the achieved air temperature reduction [7, 15, 16].

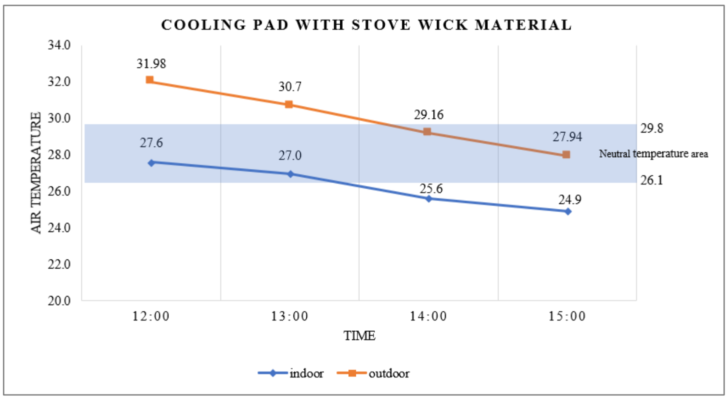


Fig 7. Air temperature without cooling pad

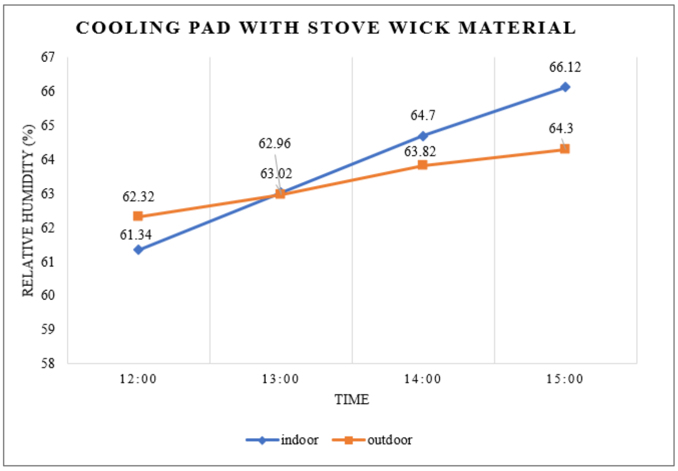


Fig 8. Air humidity without cooling pad

At 2.00-3.00 pm, there is increase in air humidity by 0.9-1.8%. However, there is a decrease of 0.06% at 1.00 pm. This air humidity reduction is very small leading to an exception that hour (Figure 8).

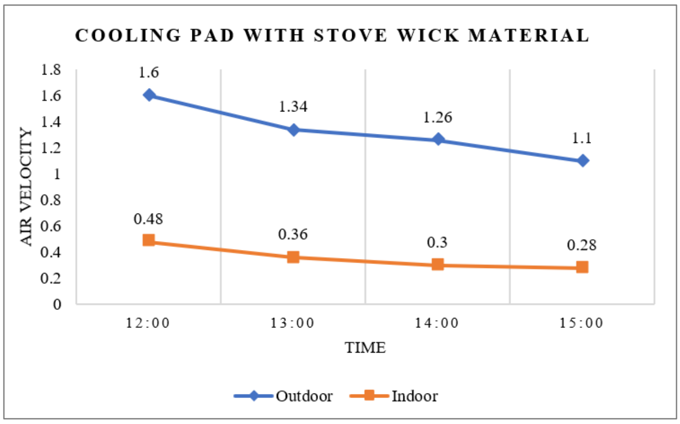


Fig 9. Air velocity without cooling pad

The air velocity outside the room is very high but the air velocity that enters the room has reached the comfort standard which ranges from 0.3 – 0.5 m / s per hour (Figure 9). This condition is an expected condition when applying a cooling pad, namely a decrease in air temperature and humidity at 12.00-1.00 pm and air velocity can still be felt by residents. This happens for only 1 hour so that at 1.00-3.00 pm further research is needed to overcome the increase in air humidity.

Table 2. The comparison before and after use of a cooling pad

Variable	Without cooling pad				With cooling pad			
	12.00	1.00	2.00	3.00	12.00	1.00	2.00	3.00
Air temperature	32.1	33	32.9	30	27.6	27	25.6	24.9
Air humidity	64.8	64.2	65.8	73.8	61.3	63.0	63.8	64.3
Air velocity	0.6	0.7	0.5	0.4	0.5	0.4	0.3	0.3

Table 2 illustrates the differences before and after the use of the cooling pad. This study confirms the findings of previous researchers that the implementation of a cooling pad with a DEC system can lower the air temperature but is not accompanied by a reduction in air humidity [7, 16, 17]. However, air velocity in the range of 0.3 - 0.5 m/s already provides comfort for the occupants inside the room. In this study, there is a need for other options to decrease the indoor air humidity. For instance, installing a ceiling fan that can increase the air velocity to over 1 m/s [20, 21]. Nevertheless, other techniques should also be explored, such as a combination of direct and indirect evaporative cooling [16].

4 Conclusion

The application of the evaporative cooling system directly with the stove axis material has an impact on decreasing air temperature but has not been followed by a decrease in air humidity. At 12.00-3.00 pm the air temperature decreased by 1.2 -1.9 degrees followed by a decrease in air humidity at 12.00-1.00 pm by 0.06% and an increase in air humidity at 1.00 - 3.00 pm by 0.9-1.8%. The wind speed in the chamber has reached the thermal comfort standard ranging from 0.3-0.5 m/s.

When referring to thermal comfort standards, a concomitant decrease in air temperature and air humidity is expected. But in this study, several options were needed to reduce air humidity to achieve thermal comfort. One of the options discussed in previous research is the use of fans which are considered the optimal solution, especially in terms of cost.

This study recommends that an evaporative cooling system directly with stove wick material can be applied to simple flats for rent with studio unit types. More research is needed to determine the effectiveness of the fan if added in this case study.

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