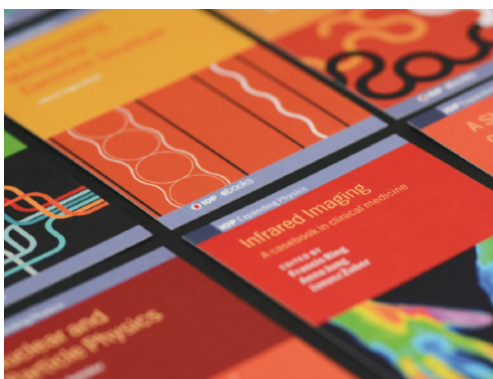


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## Fundamental design of thermoelectrical nature air conditioning system in small room for living cat (mammalian)

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# Fundamental design of thermoelectrical nature air conditioning system in small room for living cat (mammalian)

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**Abstract.** Living mammalian especially European cats will face some problems when traveling from cold ambient in Europe to hot ambient country. Some of the problems are, these cats will become panting when exposed to the high temperature of ambient for a short term. Also, for a long term exposed to high temperature, the cats will experience heat stress and hair loss. The objectives of this study are on cat thermal comfort, cooling load for cat compartment, and analysis of air flow to achieve the desired temperature for the cat compartment using CFD simulation. In this study, three parts of analysis will be considered in CFD simulations which are the thermal distribution for four Peltier plates with aluminium heat sink using ANSYS Transient Thermal, air flow in the ducting to a cold heat sink, and air flow distribution in cat compartment using ANSYS Fluent. The temperature for the Persian cat's thermal comfort is around 20-25°C. Cooling load gain from designed portable cat compartment with the desired space is 177 W. By ANSYS Transient Thermal, time taken for heat sink change from 22°C to 12°C is around 200-250 seconds. Then, by using ANSYS Fluent, the temperature of initial air temperature in the ducting when flow through a cold heat sink was changed from 27.15°C to 20.93°C by simple cooling. Next, the average air temperature in the cat's compartment is 23.83°C that achieved average thermal comfort for mammal or Persian cat which is 20-25°C of dry bulb temperature. However, the study only focuses on steady-state dry air simple cooling analysis only with the laminar flow as a preliminary result by CFD simulation before build the actual portable cat compartment. The dry air simulation can be assumed similar as humid air for simple cooling process only proved by the comparison of the same cooling capacities values towards the different value of absolute humidity.

## 1. Introduction

Hundred million of cats are kept as pets around the world. Siamese or Oriental Shorthair cats were categorized as a very light breed, the Persian cat as a light breed, the Norwegian Forest and the Siberian Cat as a large breed, and the Maine Coon cat as a giant breed [1]. In general terms, long-haired cats can tolerate much colder temperature than short-haired cats [2]. Pet lovers around the world willing to spend a lot of money on their pet's life care. Nowadays, cat's exhibitions or tournaments are held around the world. Mostly, when they are traveling with their pets from Europe to other hot and humid country, the cat's fur will fall due to expose towards high ambient temperature. Thus, the air conditioning system for a portable cat compartment is needed to overcome these



problems. By applying computer analysis software, dry air simulation is an attempt before designing an air conditioning system using thermoelectric to achieve and maintain the desired temperature for the cat's compartment. All the variables and parameters in the simulation can be changed in order to find the best airflow system. Also, to improve the efficiency of the cooling capacity of the thermoelectric to give maximum heat exchange from air inside the confined space to the outside.

Thermal comfort for a mammal is between 18.5 °C to 27 °C of air temperature and 30-70% of relative humidity. According to J. Physiol [3], some experimental study had been done to analyze the reaction of a cat in a cage when the temperature is increased. When the surrounding temperature increase from 25 °C to 38 °C, the cat becomes excited active, pacing about the cage and stretching the wall. Thermoneutral zone is the minimum temperature required to maintain body temperature by using a minimum amount of energy. From estimation, 15-20 °C for long-haired cat breeds and 20-25 °C for short haired cat breeds [4]. Yet most cat housing areas in homes and laboratories are maintained closer to  $22 \pm 2$  °C for long-haired cat [5]. Thermoelectric module (TEM) consists of an arrangement of P-type and N-type of semiconductor which can convert either electric power to thermal power or thermal power to electric power [7]. When there is some temperature difference is placed on the plates, the device can convert heat energy into electrical energy [8]. Cooling or heating energy can be produced through the flowing of electrical current into the module [9]. The cooling capacity is suitable to cover small cooling loads. The coefficient of performance of thermoelectric is less than a conventional air conditioning system. Some popular advantages of thermoelectric are small size, no chemical reaction, low energy consumption, and suitable for small cooling loads [10].

## 2. Related equations

### 2.1. Analysis of cooling load

Heat can be transferred in three different modes which are conduction, convection, and radiation. The cooling load can be calculated by adding the rate of heat transfer from conduction from the surrounding through the wall, natural convection from outside of the compartment, and thermal radiation emits from the cat's body.

$$\text{Total cooling load} = \dot{Q}_{cond} + \dot{Q}_{conv} + \dot{Q}_{rad} \quad (1)$$

$$\dot{Q}_{total} = \frac{T_1 - T_2}{R_{total}} \quad (2)$$

$$R_{conduction} = \frac{\Delta x}{kA} \quad (3)$$

$$R_{convection} = \frac{1}{hA_s} \quad (4)$$

$$R_{radiation} = \frac{1}{\epsilon \sigma A_s} \quad (5)$$

Where,  $T_1$ = temperature at point 1 (K),  $T_2$ = temperature at point 2 (K),  $k$  = thermal conductivity ( $\text{W/m}\cdot\text{K}$ ),  $\Delta x$  = Thickness (m),  $A$ = surface area of the wall ( $\text{m}^2$ ),  $h$  = convection heat transfer coefficient ( $\text{W/m}^2\cdot\text{K}$ ),  $A_s$ = Surface area contact with the fluid ( $\text{m}^2$ ),  $\sigma$  = Stefan Boltzmann constant ( $\text{W/m}^2\cdot\text{K}^4$ ) and  $\epsilon$  = emissivity ( $\text{W/m}^2\cdot\text{K}^4$ ).

### 2.2. Convection of heat transfer coefficient

The convection heat transfer coefficient  $h$  is not a property of the fluid. The value of natural convection heat transfer coefficient of air, the properties of air at the film temperature can be obtained in APPENDIX B. Thus, the natural convection of heat transfer can be calculated in equation 8 based on Rayleigh number and Nusselt number equations.

$$Ra_L = \frac{g\beta(T_\infty - T_s)L_c^3}{\nu^2} (Pr) \quad (6)$$

Where,  $g$  = Gravitational acceleration ( $m/s^2$ ),  $\beta$  = Volume expansion coefficient ( $K^{-1}$ ),  $\nu$  = Kinematic viscosity ( $m^2/s$ ),  $Pr$  = Prandtl number,  $L_c$  = Characteristic length,  $T_s$  = Surface temperature (K) and  $T_\infty$  = Outside temperature (K).

$$Nu = 0.59(Ra_L)^{\frac{1}{4}} \quad (7)$$

$$h = \frac{k}{L_c} Nu \quad (8)$$

Where,  $Ra_L$  = Rayleigh number,  $h$  = convection heat transfer coefficient ( $W/m^2 \cdot K$ ) and  $k$  = thermal conductivity ( $W/m \cdot K$ ) and  $L_c$  = Characteristic length ( $m$ ).

### 2.3. Cooling capacity for thermoelectric

Based on the cooling capacity of thermoelectric, the value of voltage and electric current can be determined by this formulation from equation (9).

$$\dot{Q}_{in} = \alpha T_c I - \frac{1}{2} R I^2 - k(T_H - T_c) \quad (9)$$

Where,  $\alpha$  = Seebeck coefficient ( $V/K$ ),  $k$  = thermal conductivity ( $W/m \cdot K$ ),  $R$  = System resistance ( $\Omega$ ),  $I$  = System current (A),  $T_c$  = temperature cold (K) and  $T_H$  = Analysis of cooling load.

### 2.4. Lumped system

The formula to determine heat sink temperature after contact with the Peltier plate can be assumed the same due to small thickness by using lump system analysis formulation in equation (10).

$$Bi = \frac{hL_c}{K} \quad (10)$$

Where,  $h$  = convection heat transfer coefficient ( $W/m^2 \cdot K$ ) and  $k$  = thermal conductivity ( $W/m \cdot K$ ). To use lump system analysis, the value of  $Bi$  must be less than 0.1.

$$b = \frac{hA_s}{\rho V C_p} \quad (11)$$

Where,  $h$  = convection heat transfer coefficient ( $W/m^2 \cdot K$ ),  $A_s$  = Surface area ( $m^2$ ),  $\rho$  = Density ( $kg/m^3$ ) and  $C_p$  = specific heat ( $kJ/kg \cdot K$ ).

### 2.5. Velocity analysis

Value of air velocity needed in this system can be determined by mass flow rate, enthalpy differential from the psychrometric chart, and cooling load calculation. All the formulation can be used as below.

$$\dot{m} \times \Delta h = \text{cooling load from the system} \quad (12)$$

$$\dot{V} = \dot{m} \times v \quad (13)$$

$$V = \frac{\dot{V}}{A} \quad (14)$$

Where,  $\dot{m}$  = mass flowrate ( $kg/s$ ),  $\Delta h$  = enthalpy differential ( $kJ/kg \cdot K$ ),  $\dot{V}$  = Volume flowrate ( $m^3/s$ ),  $v$  = specific volume ( $m^3/kg$ ) and  $V$  = air velocity ( $m/s$ ).

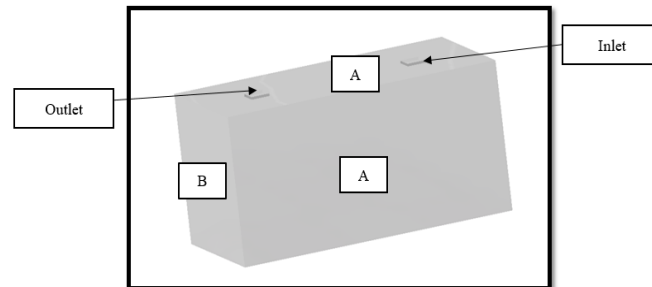
## 3. Methodology

### 3.1. Cat thermal comfort

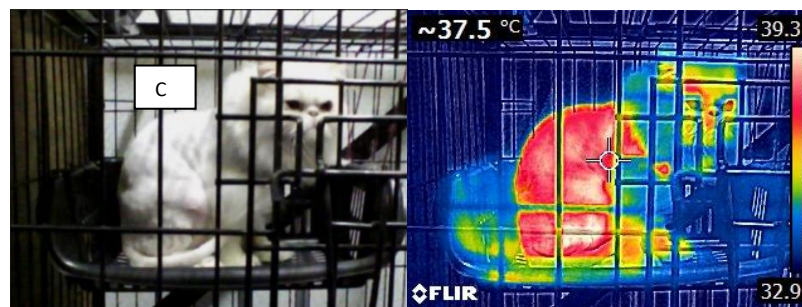
From estimation, temperature for cats use minimum energy to maintain their body temperature are around 15-20 °C for long-haired cat breeds and 20-25 °C for short haired cat breeds [4]. Yet most cat housing areas in homes and laboratories are maintained closer to  $22 \pm 2$  °C for long-haired cat [5]. In this case, by taking the average of thermal comfort of mammals which are 20°C to 25 °C of air

temperature and 40% to 60% of relative humidity as the thermal comfort to keep prevent hair loss and heat stress for European cat which is Persian cat.

### 3.2. Total cooling load



**Figure 1.** Compartment.



**Figure 2.** Cat surface temperature.

From Equation 1 in methodology, there are conduction and convection from the surrounding. Then, thermal radiation from the cat's body.

$$\text{Total cooling load} = 111 \text{ W}(\dot{Q}_{cond}, \dot{Q}_A) + 34 \text{ W}(\dot{Q}_{conv}, \dot{Q}_B) + 32 \text{ W}(\dot{Q}_{rad}, \dot{Q}_C) = 177 \text{ W}$$

Based on the calculation of subsidiary law in heat transfer. Total cooling load gained is 177 W.

### 3.3. Velocity at the inlet of the ducting

Mass flow rate: Equation 12,  $\dot{m} = 0.0151 \text{ kg/s}$ .

Volume flow rate: Equation 13,  $\dot{V}_{in} = 0.01306 \text{ m}^3/\text{s}$ .

Area of the ducting cross-sectional area,  $A = 6.4 \times 10^{-3} \text{ m}^2$

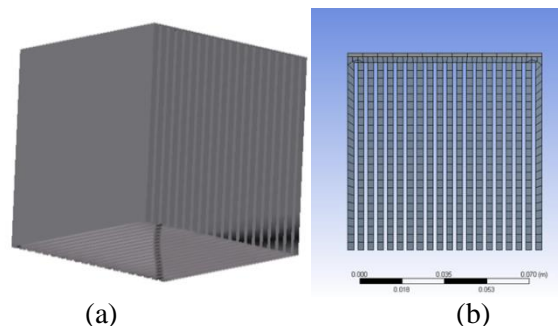
Inlet velocity: Equation 14,  $V_{in} = 2.01 \text{ m/s}$

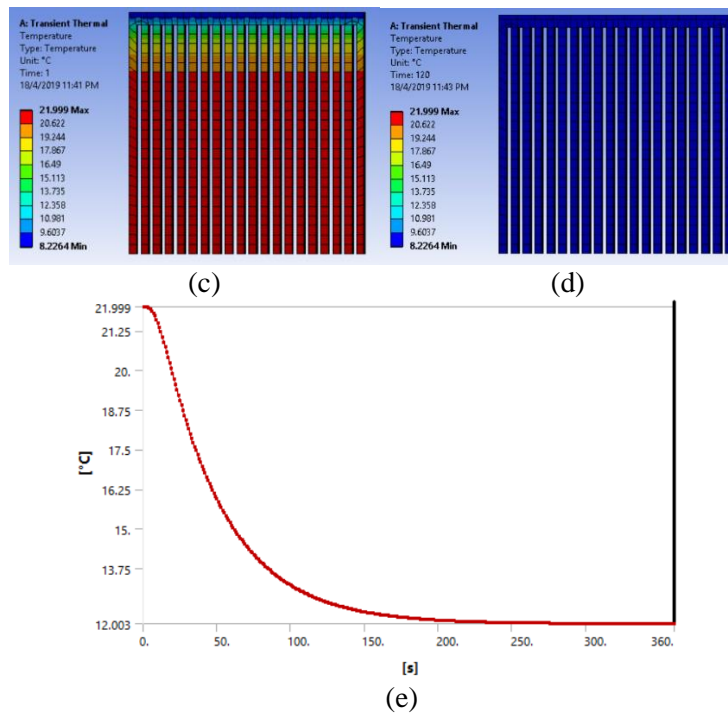
Thus, velocity inlet and outlet of the ducting is 2 m/s each can be assumed.

## 4. Result and Discussion

### 4.1. Heat sink

The heat sink thermal distribution simulation using ANSYS Transient thermal analysis.



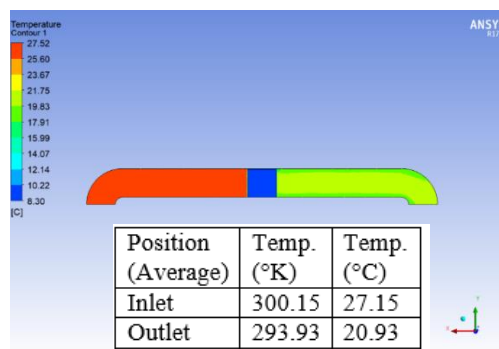


**Figure 3.** a) Heat sink geometry, b) meshing, c) at 1 second, d) at 120 seconds, and e) graph temperature vs time.

By observing the graph in Figure 3, the behavior of the graph is inversely proportional between temperature and time. The temperature aluminum heat sink from 22 °C at room temperature decrease to 12 °C following the Peltier plate’s temperature. Time taken needed for the heat sink become 12 °C is around 200 seconds to 250 seconds only.

4.2. Ducting

Airflow in the ducting simulation using ANSYS Fluent.



**Figure 4.** Temperature distribution.

Figure 4 shows the average temperature of dry air in the ducting changed from 27.15 °C to 20.93 °C of average outlet temperature after going through the constant temperature of the heat sink at 12 °C.

4.3. Compartment

Airflow in the ducting simulation using ANSYS Fluent.

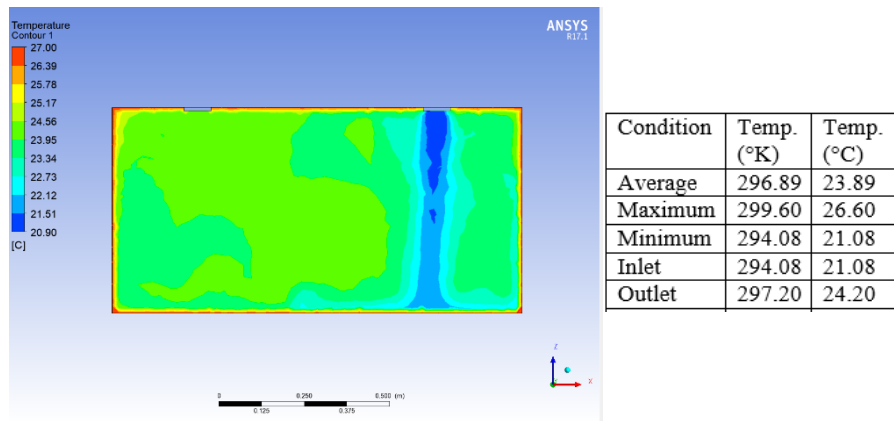


Figure 5. Temperature distribution.

Then, the average temperature at the compartment is 23.89 °C can be seen in Figure 5. The average inlet temperature of the compartment to the outlet temperature changed from 21.08 °C to 24.04 °C. The average temperature in the compartment achieved the average thermal comfort of mammal or cat which is air temperature between 20 °C to 25 °C.

4.4. Compartment analysis

There are some possible constraints that may affect the values of temperature which are dry air analysis using software with humid air in real life. Referring data of simple cooling at Figure 6, by increasing the absolute humidity from 0 g/kg to 50 g/kg and 100 g/kg, the air temperature at the outlet of the ducting can be determined for same cooling capacity. This data from the calculations will prove the similarity relationship between dry and moist air simulation with the same cooling capacity and differences values of the absolute humidity as long as it is a simple cooling process in Table 1.

From the graph in Figure 7, the similarity of dry air and humid air relationship can be seen when increasing the absolute humidity, the changes of the inlet to outlet temperature are the same. The final temperature did not reach or below than the dew point temperature to prove simple cooling process by this system. By this relationship, this dry air simulation can be used regardless the value of absolute humidity as a preliminary result as long as a simple cooling process before starting to design a cooling system for cat’s compartment with actual humid air in the real life.

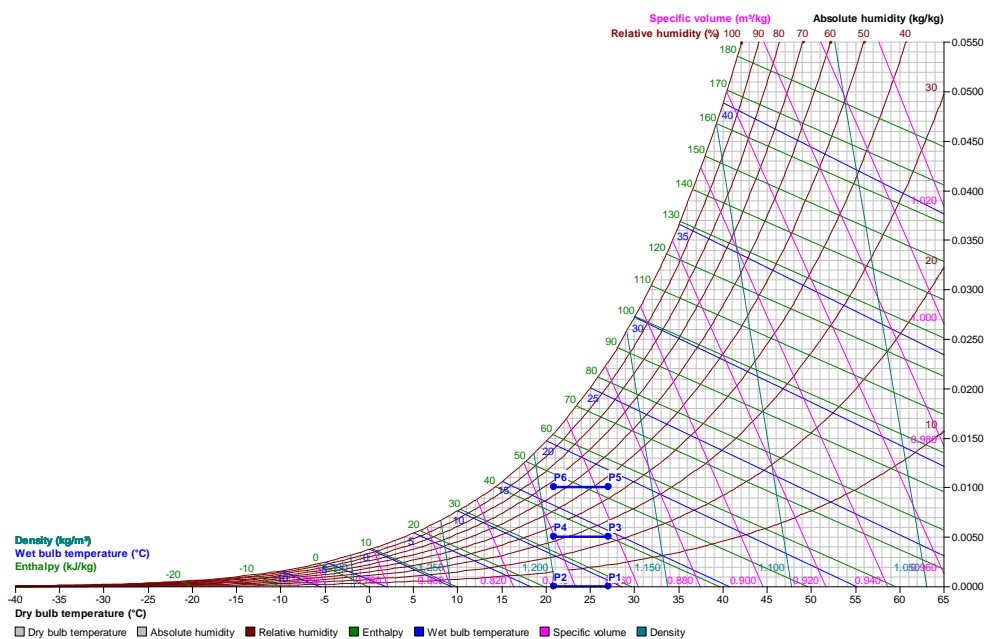
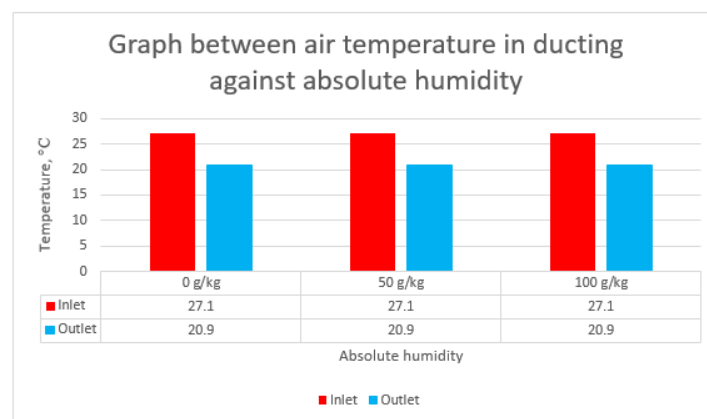


Figure 6. Simple cooling for 0 g/kg, 50 g/kg, and 100 g/kg of absolute humidity.



**Table 1.** Comparison data gained for different absolute humidity between 0 g/kg, 50 g/kg, and 100 g/kg

Condition from the inlet of ducting	Cooling load	Mass flow rate, $\dot{m}$	Mass flow rate differential, $\Delta\dot{m}$	Enthalpy differential, $\Delta h$	Outlet temperature
27.1 °C to 20.9 °C at 0 g/kg of absolute humidity from simulation	94.5 W	0.0150 kg/s	Decrease 0.0001 kg/s	6.3 kJ/kg	20.9 °C
27.1 °C at 50 g/kg of absolute humidity	94.5 W	0.0149 kg/s		6.34 kJ/kg	20.9 °C
27.1 °C 100 g/kg of absolute humidity	94.5 W	0.0148 kg/s		6.38 kJ/kg	20.9 °C

**Figure 7.** Simple cooling differential temperature with 0 g/kg, 50 g/kg, and 100 g/kg of absolute humidity.

## 5. Conclusion

The portable cat compartment works to overcome problems such as heat stress and hair loss toward European cats when traveling from cold to a hot environment. Cat thermal comfort is the target point to be achieved and regulated in the portable cat compartment. From the survey at Jabatan Perkhidmatan Veterinar Negeri Perlis, there is no specific temperature and humidity for cat's thermal comfort. A cat can adapt to surrounding temperature when living in a new environment. But, for traveling for a certain period of time in a hot environment, the temperature of the compartment needs to be regulated to maintain the cat's thermal comfort. Thus, by taking the average of thermal comfort of mammals which are 20°C to 25°C of air temperature and 40% to 60% of relative humidity as the thermal comfort to keep prevent hair loss and heat stress for European cat which is Persian cat.

The cooling loads for the portable cat compartment can be calculated by using subsidiary law in heat transfer which are Fourier law of conduction, Newton law of cooling in convection, and Stefan Boltzmann law in thermal radiation. Total cooling load from the cat's compartment obtained by the calculations is 177 W. By these cooling load, the velocity for the inlet ducting with 0.0064 m<sup>2</sup> of the area is 2 m/s. Thus, 4 pieces of Peltier plates will be used with 6 A of current, 6 V of voltage, and around 50-60 W each. The COP of the Peltier module is 1.42 which is likely an efficient device. All four Peltier plates will be attached to an aluminum heat sink with 8.3 °C.

By ANSYS Transient Thermal, time taken for heat sink change from 22 °C to 12 °C is around 200-250 seconds. Then, by using ANSYS Fluent, the temperature of initial air temperature in the ducting was changed from 27.15 °C to 20.93 °C by simple cooling. Next, the average temperature in the cat's compartment achieved is 23.83 °C which is achieved average thermal comfort for mammal or Persian cat which is 20-25 °C of dry bulb temperature. But this data using steady-state simulation with laminar flow and fully dry air. This dry air simulation same as humid air simulation had been



proved in discussion before which is only for simple cooling analysis. All three objectives had been achieved in this study.

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