Eco-cooler Analysis for Room Temperature Reduction

Benya Kasantikul

Department of mechanical Engineering, Faculty of Engineering, Kasetsart University, KamPhaeng Saen Campus, Thailand

benya.k@ku.th

Abstract. *This study was to examine reducing a $4.2 \times 3.1 \times 3.3$ m^3 room temperature by an Eco-cooler instead of using electric energy. The Computational Fluid Dynamics (CFD) program was used to test the effect of heat transfer and to predict the fluid flowing behavior so that the temperature resulting from the Eco-cooler could be analyzed. In the experiment, the air velocity range was set between 1-3 m/s for comparison between the temperature obtained from the actual experiment and one from the analysis by the CFD program. This study revealed that the results from the CFD program and the experimental results were very similar; thus, their discrepancy was between 0.01 – 2.37 % and the room temperature could be reduced by 1-3 degrees Celsius. The rectangular eco-cooler can more reduce the room temperature. The type-2 Eco-cooler made from 500-milliliter rectangular bottles gives the highest reducing room temperature, 3.66 ℃. In addition, reducing the room temperature depends on the air velocity and size of the Eco-cooler.*

1. Introduction

Hot weather is a common problem throughout the world. To solve this problem, the technologies of electric fans and air conditioners are generally used. However, the solution is quite costly and wastes electrical resources, particularly in some areas where people do not have access to electricity or where the electricity is not enough to supply power to the air conditioners. In addition, higher temperature affects the work of people according to the research of [1-3] suggesting that people's performance decreases when the room temperature rises.

The eco-cooler which has been designed by Ashis Paul [4] is a cooling technology without electricity which is cheaper as compared to other technologies. It is a device which consists of grids of nozzles made from repurposed bottles which are cut into half and the brims are inserted into a cardboard sheet. The Eco-Cooler is then fixed to a window which is in the direction of maximum air flow so that the wider end of the bottles faces outside. The air passes through the bottles and gets compressed while passing through the neck. The compressed air while leaving the brim will expand rapidly and gives cooler air. [5] studied the cooling of air is observed without any application of external source, zero electricity air conditioner which reduced temperature of 2.7 °C. Computational Fluid Dynamics (CFD) is more diverse and can provide more comprehensive data for temporary indoor temperature simulations. Popovici [6] studies cooling and air conditioning (HVAC) systems in summer and winter using ANSYS- Fluent. Fang and the Board [7] use integrated CFDs and network models to calculate distribution. The temperature of the air in the air-conditioned office.

The objectives of this research are to design an Eco-cooler suitable to reduce the room temperature of $4.2 \times 3.1 \times 3.3$ m^3, to compare the temperature results from the Computational Fluid Dynamic (CFD) analysis and the real experiment to find the discrepancy and to study its economic feasibility and worthiness.

2. Review of Related Literatures

A nozzle is a device designed to control the direction or characteristics of a fluid flow (especially to increase velocity) as it exits (or enters) an enclosed chamber or pipe. A nozzle is often a pipe or tube of varying cross- sectional areas and it can be used to direct or modify the flow of a fluid (liquid or gas). Nozzles are frequently used to control the rate of flow, velocity, direction, mass, shape, and/or the pressure of the stream that emerges from them. In a nozzle, the velocity of fluid increases at the expense of its pressure energy [8]. Its working principle is shown in Fig. 1. In the nozzle solution, 3 equations are used according to the following laws.
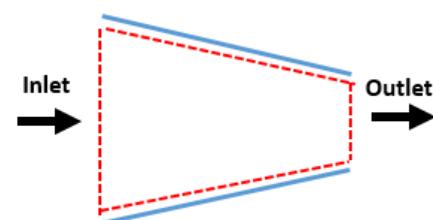

Fig. 1: Flow direction of fluid through the Nozzle [8]

1. The law of conservation of energy

This law means that energy can neither be created nor destroyed; rather, it can only be transformed or transferred from one form to another as shown by the equation (1) [8]:

$$q + (h_{in} - h_{out}) + 0.5(c_{in}^2 - c_{out}^2) = 0 \qquad (1)$$

2. The law of conservation of mass

According to the law of conservation of mass, the mass of the products must equal the mass of the reactants as shown by the equation (2) [8]:

$$\rho_{in} \bullet c_{in} \bullet A_{in} = \rho_{out} \bullet c_{out} \bullet A_{out} \qquad (2)$$

3. The law of ideal gas

The equation of this law is (3) [8]:

$$P = \rho \bullet R \bullet T \qquad (3)$$

;where q = heat transfer ratio (kJ/kg)

   h_i, h_o = in and out enthalpies (kJ/kg)

   c_{in}, c_{out} = in and out air velocity (m/s)

   ρ_{in}, ρ_{out} = in and out air densities (kg/m³)

   A_{in}, A_{out} = in and out areas (m²)

   P   = pressure (N/m²)

   R   = constant of air

   T   = absolute temperature (K)

In addition to the above laws, CFD simulation must be performed in order to help preliminary analysis. The simulations can be done in steady state regime, using turbulent flow and k-ε model, appropriate for evaluation of heat transfer and airflow for closed system [9]. Numerical simulation is conducted by CFD tool, the differential equations of heat transfer and fluid mechanics were solved as following equations [10]:

Momentum equation:

$$\frac{\delta}{\delta t}(\rho \vec{v}) + \nabla \bullet (\rho \vec{v} \vec{v}) = -\nabla p + \nabla\left(\overset{=}{\tau}\right) + \rho \vec{g} + \vec{F} \qquad (4)$$

Energy conservation:

$$\frac{\delta}{\delta t}(\rho E) + \nabla \bullet (\vec{v}(\rho E + p)) = -\nabla \bullet \left(\sum_j h_j J_j\right) + S_h \quad (5)$$

Conservation of mass:

$$\frac{\delta}{\delta t} + \nabla \bullet (\rho \vec{v}) = S_m \qquad (6)$$

;where: ρ = densities (kg/m³)

   p = pressure (N/m²)

   v = overall velocity (m/s)

   t = time (s)

   τ = shear stress (N/m²)

   g = gravitational acceleration (m/s²)

   F = force vector (N)

   E = total energy (J)

   h = enthalpy (J/kg)

   J = diffusion flux (kg/m²-s)

   S_h = Source of heat added

   S_m = Source of mass added

3. MATERIALS AND METHODS

3.1 Materials

In the study, the following equipment were used:

1. a cardboard sheet of Eco-cooler consisting of nozzle grids, a test room of $1 \times 1 \times 2$ m³ because of the limitation of test area, and an experimental room of $4.2 \times 3.1 \times 3.3$ m³ (real working room of the staff). Nozzles are designed from the bottleneck of drinking water bottles sale in the market.

2. Anemometer

3. DHT22 temperature sensor

4. Arduino board and program

5. Computational Fluid Dynamic (CFD) program

3.2 Methods

3.2.1 Determining the temperature and air flow in the experimental room by CFD program

The CFD program was used to analyze temperature and fluid dynamics results in a test room of $1 \times 1 \times 2$ m³ (Fig. 2) using the circular and rectangular eco-coolers (Fig. 3) to find the temperature in the experimental room and the air flow behavior. The configuration steps in the program are as follows: 1) to set the scope of the Eco cooler grids, 2) to set the nozzle entrance conditions including the inlet air velocity and temperature, 3) to specify the conditions of the experimental room such as the friction of the air that

hits the room wall in an adiabatic style and 4) to specify other conditions such as air density, gravity of the Earth, smoothness and duration.
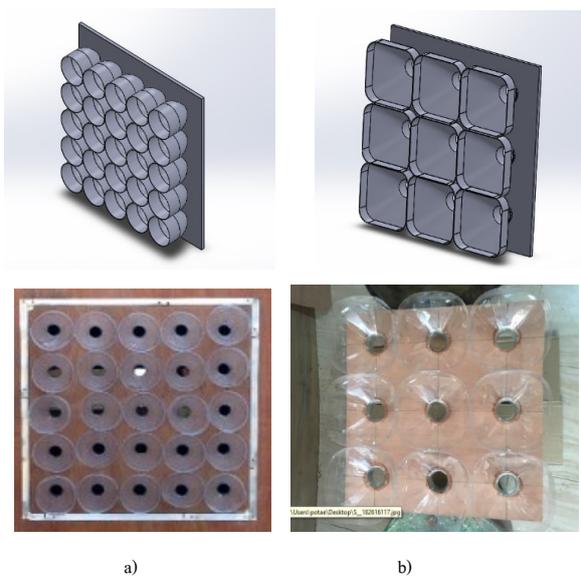
Boundary Conditions of the CFD Analysis

1. steady state of air flow

2. no-slip condition

3. air density (kg/m^3)

4. inlet air velocity (m/s)

5. the gravity of Earth (9.81 m/s^2)

6. adiabatic heat transfer

In addition, the mathematical model was also defined as follows: 1) at the nozzle entrances, the air velocity was set and the air density was set at 1.185 kg / m^3 and 2) at the nozzle exits, the outlet air pressure was set equal to the atmospheric pressure. The wall of the experimental room was specified as no-slip type where the friction between the air and the wall is calculated and heat transfer was specified as adiabatic.

Fig. 2: Dimension of Test room

a)   b)

Fig. 3: a) A circular Eco – cooler b) A rectangular Eco – cooler

### 3.2.2 Comparing the temperature and air flow in the experimental room by CFD analysis

The temperatures from the real experiment and the CFD analysis were compared under the conditions of the temperature and air velocity in the real experiment in order to find the discrepancy in terms of error percentage.

3.2.3 Designing various types of Eco-cooler

To find the best eco-cooler for the room temperature reduction, 3 types of the Eco – cooler were designed as shown in Fig.4.

a) Type-1 Eco-cooler consisting of 9 of 6-liter rectangular bottles placed as 3 x 3 grids on a 48×48 -cm^{2}cardboard sheet

b) Type-2 Eco-cooler consisting of 64 of 500-milliliter rectangular bottles placed as 8 x 8 grids on a 48×48 -cm^{2}cardboard sheet

c) Type-3 Eco-cooler consisting of 30 of 1, 1500-milliliter rectangular bottles placed as 5 x 6 grids on a 48×48 -cm^{2}cardboard sheet

Type 1   Type 2   Type 3
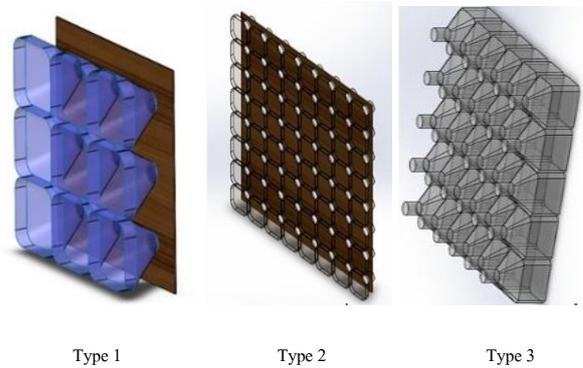
Fig. 4: 3-Type Eco-coolers including Type 1, 2 and 3

3.2.4 Designing and testing the Eco-cooler suitable to a room of 4.2x3.1x3.3 m^3

A rectangular Eco – cooler consisting of 120 of 500-milliliter rectangular bottles placed as 15 x 8 grids for cooling a test room of 4.2×3.1×3.3 m^3 was designed and tested (Fig.5-6).
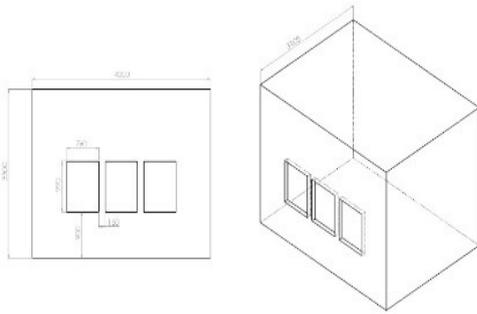
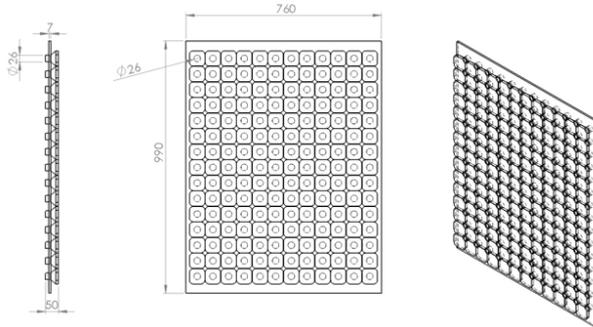**Fig. 5:** Dimension of A test room of 4.2×3.1×3.3 m³

Fig. 6: A rectangular Eco – cooler for a room of 4.2×3.1×3.3 m³

4. RESULTS AND DISCUSSIONS

4.1 Comparison of the temperatures from a test room of 1×1×2 m³ by the real experiment and the CFD analysis

As shown in Table 1, the experimental results of using the circular and rectangular eco-coolers (Fig. 3) show that the internal and external temperatures are slightly different, perhaps because the cooling room has a vent that prevents the air from circulating to where the temperature measured. However, they are valid and in accordance with the energy conservation rule.

Eco-cooler type	Average velocity (m/s)	Temperature from Experiment (°C)	Temperature from CFD (°C)	Discrepancy (%)
Circular	2.6	32.50	32.80	0.914
Rectangular	2.6	31.50	32.00	1.562

Table 1 The comparison of the results of the circular and rectangular Eco-coolers from the experiment and the CFD analysis.

According to the CFD analysis of the temperature reduction by the air velocity average 2.6 m/s and the temperature distribution as shown in Fig. 7, although the Eco-cooler consisting of rectangular bottles can lower the temperature better than that consisting of circular ones; the Eco-cooler consisting of circular bottles has, however,

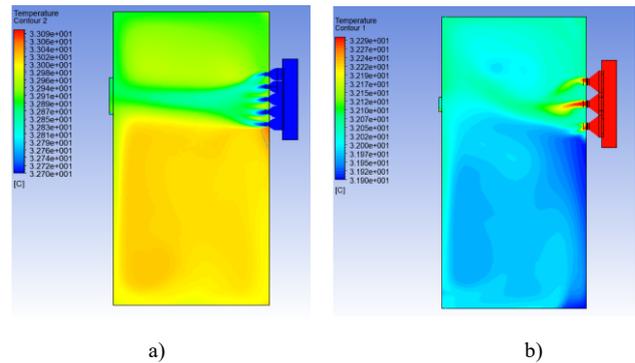better air distribution, therefore it causes less discrepancies than that consisting of rectangular bottles.

a)   b)

Fig. 7: The temperature reduction by the air of 2.6-meter/second velocity through a) the Eco-cooler consisting of circular bottles and b) the Eco-cooler consisting of rectangular bottles.

4.2 Result from the CFD analysis in designing each type of the Eco-cooler

According to Fig. 8, since the Eco-cooler consisting of rectangular bottles could lower the temperature better than that consisting of circular ones; another 3 types of the Eco-cooler consisting of 3 different sizes of rectangular bottles were designed and the performance of each type was tested by numerical simulation. The simulation results revealed as follows: the Type-1, Type-2 and Type-3 Eco-coolers could reduce the temperature from 35 °C to 33.74 °C, from 35 °C to 32.42 °C and from 35 °C to 33.62 °C respectively. In sum, the Type-2 Eco-cooler could reduce the temperature most.
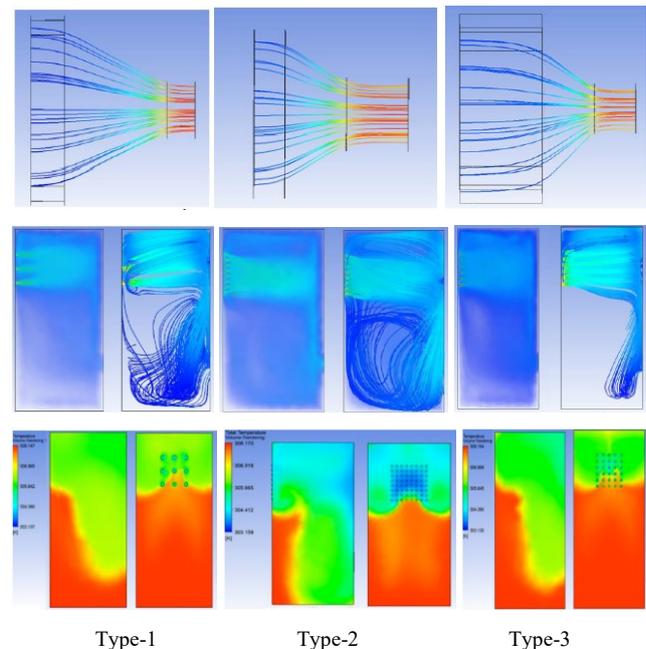

Type-1   Type-2   Type-3

Fig. 8: Volume Rendering and Streamline of the air velocities and room temperatures from the CFD and the Type-1, Type-2 and Type-3 Eco-coolers.

4.3 Comparison of the temperatures of an actual work room of 4.2 × 3.1 × 3.3 m³ from the real experiment and the CFD

Due to the simulation results show (previously in 4.2) that the Type-2 Eco-cooler can most reduce the temperature, it was then simulated in an actual work room of 4.2 × 3.1 × 3.3 m³ with 3 windows. Since the area of each window was equal to the nozzle grids of 180 upper-half-cut bottles, the simulation of the Type-2 Eco-cooler was conducted with the window 1, 2 and 3 respectively with the range of air velocities between 1-3 m/s and the results are shown in Table 2. In the experiment of 2 windows, based on equation (2) the test is chosen to put them next to each other.

Velocity in (m/s)	Outside Temperature(°C)	Room Temperature from CFD (°C)		
		180-nozzle	360-nozzle	540-nozzle
1	35	34.11	33.43	33.03
2	35	34.05	33.28	32.75
3	35	33.99	33.10	32.51

Table 2 The simulation results of the temperature reduction from the CFD of the rectangular Eco-coolers with the velocity range of 1-3 m/s.

As shown in Fig. 8, the simulation results of the room temperature reduction from the CFD of the Type-1, Type-2 and Type-3 Eco-coolers with the velocity of 3 m/s. Type-2 Eco-cooler reduces the temperature most so designing the Type-2 Eco-coolers in place of 1, 2 and 3 windows can reduce the room temperature at 1.97 °C, 2.25°C and 2.49 °C respectively. Fig. 9 shows the temperature distribution in the workroom.
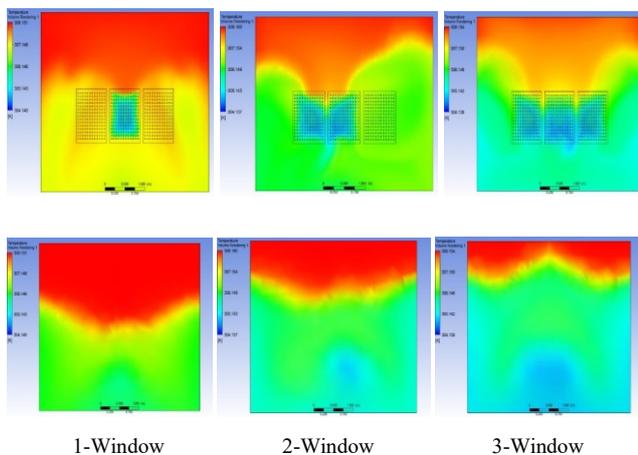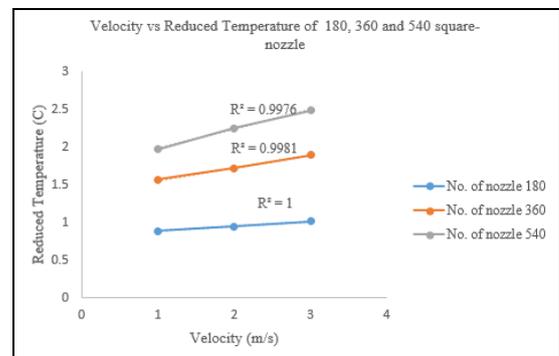

Fig. 9: The room temperature reduction from the CFD and from using the Type-2 Eco-coolers in place of 1, 2 and 3 windows respectively.

Velocity in (m/s)	Outside Temperature(°C)	Different Temperature from Experiment vs. CFD (°C) and Discrepancy (%)		
		180-nozzle	360-nozzle	540-nozzle
1	34.78	34.25 (0.41%)	33.18 (0.76%)	33.01 (0.07%)
2	34.65	34.05 (0.01%)	33.09 (0.57%)	32.13 (1.93%)
3	34.52	33.22 (2.31%)	33.02 (0.25%)	31.76 (2.37%)

Table 3 The different temperature results from experiment vs. CFD and the discrepancies (error percentage) of the Type-2 Eco-cooler as compared to those from the CFD.

As shown in Table 3 , the room temperature reduction from the tests using the Eco-cooler in place of 1, 2 and 3 windows with the velocity of 1-3 m/s reveals the highest different temperature at 1.77 °C, 2.52°C and 2.76 °C. The discrepancy is around 0.01-2.37%.

Fig. 10 shows the room temperature reduction from using the Eco-coolers of various sizes in place in place of windows as compared with varied air velocities. Thus, the higher, the velocity is; the greater is the room temperature reduction from using the Eco-coolers of various sizes and R^2 is higher than 0.997.


Fig. 10: The room temperature reduction from using the Eco-coolers of various sizes in place in place of windows as compared with varied air velocities.

4.4 Comparison between the outside and inside temperatures of the actual working room of 4.2 × 3.1 × 3.3 m³ from the actual experiment

According to Fig. 11, the differences between the outside and inside temperatures in the test room from 8:00 to 17:00 hours are quite stable. This shows that the Eco-cooler can reduce room temperature steadily, regardless of the temperature outside of the room but when the air velocity increases, it can reduce the temperature in the room more. The experimental results are consistent with the work that has been researched. The outside temperature

tends to rise from 9-13, normally peak around 13.00 hour and after that the trend will decrease. The highest temperature reduction is at 13.00 hour with 3.66 °C, which is higher than previous work [5].
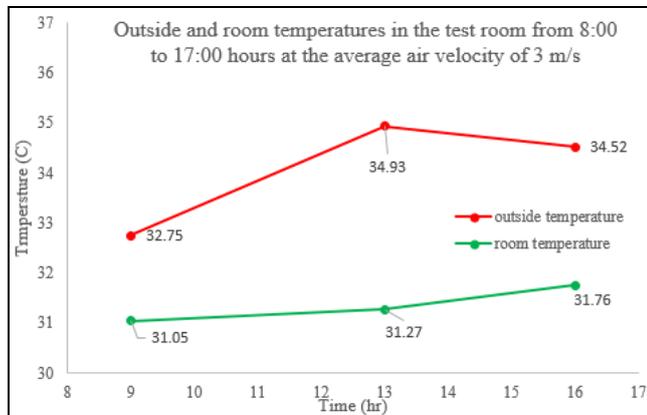
Fig. 11: Outside and room temperatures in the test room from 8:00 to 17:00 hours at the average air velocity of 3 m/s.

5. CONCLUSION

According to the experimental results from this study, the comparison between the temperature values from the experiments and those from the CFD program reveals that the average error is around 0.01-2.37%. The CFD program is useful because it helps reduce calculating complexity. Using an Eco-cooler can reduce the temperature of the 4.2 × 3.1 × 3.3 m³ room by 1-3 °C. The rectangular eco-cooler can more reduce the room temperature. From experimental results, the type-2 Eco-cooler made from 500-milliliter rectangular bottles gives the highest reducing room temperature, 3.66 °C. The room temperature reduction depends on the air velocity and size of the Eco-cooler.

Acknowledgements

References

[1] Chad, K.E. and Brown, M.M. (1995). Climatic stress in the workplace: its effect on thermoregulatory responses and muscle fatigue in female workers. Applied Ergonomics 26(1): 29-34.

[2] Maiti R. (2008). Workload assessment in building construction related activities in India. Applied Ergonomic. 39, 754-765.

[3] Lundgren Kownacki, K., Kuklane, K., Gao, C., & Holmér, I. (2013). Effects of Heat Stress on Working Populations when facing Climate Change. Industrial Health, 51(1), 3-15. https://doi.org/10.2486/indhealth.2012- 0089.

[4] Ashis Paul [Online]. Available at: https://observers.france24.com/en/20160602-bangladesh-air-conditioner-plastic-bottles-technology.

[5] Akshansh Mishra, Anish Das Gupta, Amit Kumar Mandal and Anand Singh. Zero Electricity Air Conditioning Using Phase Changing Materials. *International journal of thermal engineering*, 4(1), 2016, pp. 10–14.

[6] Popovici C G. HVAC System Functionality Simulation Using ANSYS-Fluent [J]. Energy Procedia, 2017, 112:360-365.

[7] Fang P, Liu T, Liu K, et al. A Simulation Model to Calculate Temperature Distribution of an Air-Conditioned Room[C]. International Conference on Intelligent Human-Machine Systems and Cybernetics. IEEE, 2016.

[8] Sonntag E., Borgnakke C. and Van Wylen J. (2003). Fundamentals of Thermodynamics, 6th Edition. John Wiley and Sons, USA.

[9] Schwarz W, Marchal T. Innovation in Building Design through Engineering Simulation. ANSYS, Inc.; 2009.

[10] ANSYS-Fluent, Theory Guide.

Biographies

Benya Kasantikul was born in 1974. She received her D.Eng. from Kasetsart University, Thailand, in 2014. Her research interests include energy management, agricultural waste management and natural gas equipment design.