# Development and optimization of specially designed air ventilation system combined with thermoelectric and composite desiccant unit

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**ABSTRACT**

This research focused on the enhancement of a conventional air ventilation system by using monitoring control. A specially designed system was developed to optimize the current systems in order to improve the air quality and thermal comfort in buildings. Indoor parameters, such as temperature, humidity, and air pollution ($CO_2$), were monitored and controlled. Researchers accumulated data and implemented performance analysis as a tool for assessing specially designed air ventilation systems. These practices were designed based on a concept that is dedicated outdoor air systems that were comprised of a composite desiccant unit in addition to a thermoelectric module to address tremendous latent and sensible loads of air inlet. The results of the experiment indicated that the 12 V of electrical supply to thermoelectric provided the highest COP of the system, and the temperature and humidity in the comfort zone was approximately 27 ℃ and 55%, respectively, due to this newly developed system. Furthermore, the $CO_2$ levels were lower than 1000 ppm during this research study, which were in accordance with established standards of indoor air quality.



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## 1. INTRODUCTION

The conditions of individuals can be directly impacted by the quality of the indoor environments in which they inhabit. The workplace, the home, or any venue is susceptible to a change in temperature, humidity, or air quality; thus, air quality and thermal comfort are the fundamental issues that impact the quality of life of occupants in the short or long term [1]. Maintaining good air quality is the key factor for preventing the sick building syndrome from arising, a circumstance whereby occupants experience health issues that are related to poor indoor environmental conditions. There are many methods that address the issues of the indoor air quality (IAQ) regarding building enclosures, such as the increasing amount of circulating air, the application of an air-conditioning system, which helps to reduce the air contaminant, or decrease the source of indoor and outdoor pollution [2].

The researchers in this study were faced with the challenge of developing a heating, ventilation, and air conditioning (HVAC) system that would directly impact the quality of life of a structure's occupants. The principal objectives for HVAC system improvements were designed to preserve a suitable indoor air quality while decreasing the energy consumption of the building at the same time. Good ventilation is an important element needed to produce a healthy atmosphere while creating energy cost reduction. However, the conventional air ventilation was not able to address the latent and sensible heat emissions of air before distributed to indoor environments, a factor that increased the cooling load of air conditioning. So, researchers developed this dedicated outdoor air system (DOAS) to enhance the IAQ, thermal comfort, and cooling load reduction impact of a HVAC system. A variety of innovative technologies and equipment were applied to the DOAS unit to create a better performance system which included the use of many pioneering applications relate to dehumidification in a DOAS [3]-[9], such as testing heat wheels or enthalpy wheels that are commonly used in present day ventilation systems [10]-[15].

There are several studies which have examined the role of dedicated outdoor air system as a viable tool that impacts consumers usage. These conditions, the air quality, thermal comfort, and energy use of the building, play a major role in the choices that determine which cooling unit will provide a feasible air system to deal with the sensible and latent heat of a building. In 2018, Jirod *et al* [16] studied the hybrid air ventilation system for improving the indoor environment using monitoring control. They used a combination of a silica gel unit and a thermoelectric device, the result of this arrangement indicated the system reduced the temperature, humidity, and $CO_2$ levels to a comfortable zone as established by ASHRAE 62.2. In the same year, Mihara *et al* [17] evaluated the interior environment of a building while DOAS integrated with ceiling fans (DOAS-CF) was applied. They used a thermal manikin to examine the cooling effect produced by DOAS-CF system in their test room environment. The results showed the location, indoor temperature, and the intensity of fan speed significantly influenced the cooling effect. Furthermore, they also studied the performance of DOAS-CF to enhance the energy-saving potential, perceived air quality (PAQ), and thermal comfort using a building energy simulation program and the perceptions of the occupants (subjects) in the experiment [18]. The result showed the proposed system achieved a reduction in the annual energy consumption, while the occupants of the building felt comfortable. In 2021, the thermal comfort, PAQ of occupants, and energy consumption were evaluated by using the Mihara *et al* approach [19]. These parameters were compared under two different conditions: DOAS-CF and DOAS with a fan coil unit (FCU). The result showed that DOAS-CF reached better thermal comfort when adaptation of occupant behavior was empowered. Additionally, DOAS-CF attained greater energy conservation than DOAS-FCU. Yang *et al.* [20] presented a model predictive control (MPC) unit that was developed for a DOAS, one which assisted a separate sensible and latent cooling (SSLC) system. They employed a multi objective function device to improve energy consumption and thermal comfort in buildings. The results indicated the MPC system accomplished 18% and 20% of energy saving for the single-coil air handling unit (AHU) and DOAS-assisted SSLC, respectively, as compared to the existing building management system. Moreover, the DOAS-assisted SSLC achieved better thermal comfort and humidity compared to single-coil AHU, when these systems were controlled by the MPC. Moreover, using the previously model predictive control, Chen and Norford [21] applied the thermodynamic models to evaluate the energy efficiencies of future dedicated outdoor air-cooling systems, which was coupled with an energy recovery unit (desiccant) or a renewable energy attachment (membrane). Afterwards, they compare those efficiencies against the industry benchmark, which provided an insight into beneficial prospects as well as possible limitations of each factor relating to different time scales and locations.

The results provided a clear understanding of the standards and appropriate tools needed to manage the device in order to accomplish energy conservation and increase the coefficient performance of the proposed cooling technologies relating to latent heat elimination. In this study, a specially designed air ventilation system was developed and optimized to improve the IAQ and thermal comfort for a building. The concept of proposed system was based on dedicated outdoor air system. The dedicated system was constructed by using a thermoelectric and composite desiccant unit to address the latent and sensible heat issues including to be the alternative way for old ventilation substitution. Additionally, the monitoring control system was written using an Arduino program that was created to control indoor environmental elements such as temperature, humidity, and $CO_2$ levels during this research data collection. The acquired data was used to analyzed and determined the effectiveness and efficiency of the system.

## 2. RESEARCH METHODOLOGY

The experiment was prepared to evaluate the temperature, humidity, and $CO_2$ reduction using a monitoring control system that was created by the researchers. The designation of system, the special air ventilation process, the monitoring controls, and the experimental setup were presented in this section.

### 2.1. Specially air ventilation design

The specially designed air ventilation system was designed using a thermoelectric and composite desiccant unit. A schematic of system structure is shown in Figure 1. The proposed unit contains the twelve thermoelectric strips sandwiched between two rectangular heat sinks identified as the hot side and two rectangular heatsink for cold side of the unit. The two rows of six thermoelectric (TE) strips were connected in a series. The four modules of direct-current (DC) fan were applied for air moving through the heat sink on cold side and transfer of excessive heat on hot side to the ambience. For the test, the six modules of temperature and humidity sensor (DHT22) were used to detect the indoor parameters as shown in Figure 2. The specification of TE as shown in Table 1 were employed to optimize the outdoor air parameters such as temperature, and humidity before being distributed to the indoors via the cold side and then regenerated to the composite desiccant by the hot side of the unit. In the part of a composite desiccant unit, the four rectangular heat sinks were coated with a silica gel – lithium chloride composite desiccant (SG-L40) at 1.5 mm of thickness to exchange both sensible load and latent load of the outdoor air [22]. Table 2 demonstrates the specification of devices in ventilation system.

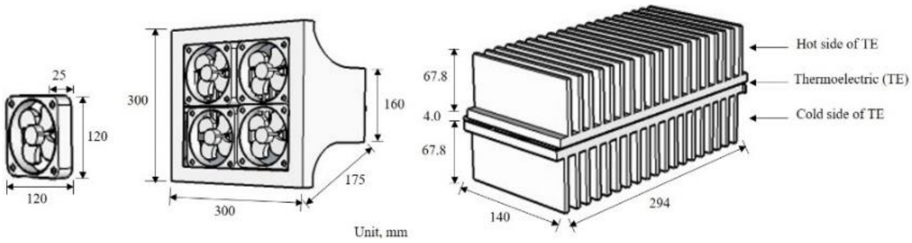


Figure 1. A schematic of specially designed air ventilation system

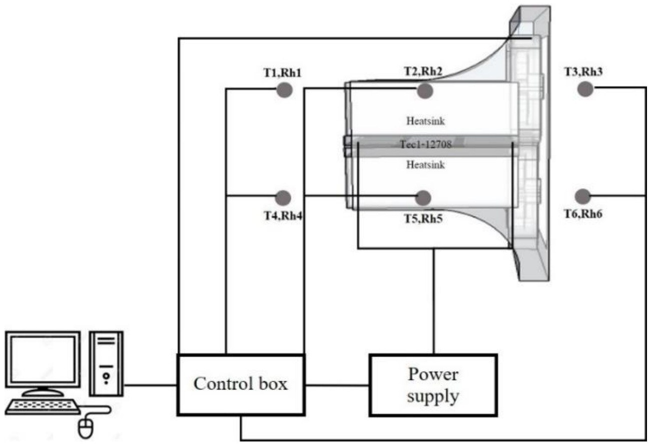


Figure 2. System configuration of monitoring sensor in specially designed air ventilation process

Table 1. Specification of thermoelectric module [23]

| Parameters | TEC1-12708 |
|---|---|
| Size (mm) | 40x40 |
| Height of module (mm) | 3.46 |
| $V_{max}$ (volt) | 15.0 |
| $I_{max}$ (amp) | 8.5 |
| $Q_{max}$ (watt) | 127.5 |
| Maximum of hot side temperature (◦C) | 160-170 |
| Maximum of different temperature (◦C) | 68 |

Table 2. Specification of special air ventilation device

| Devices | Specification |
|---|---|
| Fan module | 12VDC/4 modules |
| Thermoelectric module | 12VDC/12 modules |
| Heatsink | Size 147x140x67.8 mm/ 4 modules |
| Composite desiccant | SG-L40 |
| Temperature and humidity sensor | DHT22/ 6 modules |
| Microcontroller | NodeMCU ESP8266 |

### 2.2. Specially designed air ventilation process

The operation of specially designed air ventilation system is illustrated in Figures 3(a) and 3(b). The TE and composite desiccant unit were used to improve the indoor environment that was divided into 2 conditions. The dehumidification process, the air quality control using the ASHRAE 62.2 standard, and regeneration process as shown in Figures 3(a) and 3(b) operated simultaneously as an environment control unit.

The temperature and humidity of the outdoor air was decreased by the dehumidifier unit that supplied flow to the cold side of thermoelectric strip. Moreover, the temperature of return air was increased via the hot side of the thermoelectric module, which was used to restore desiccant, that is to discharge any remaining moisture in the saturated desiccant during the regeneration process. These processes worked simultaneously and switched modes to accomplish moisture reduction during the different process.

The psychrometric chart of special air ventilation system is shown in Figure 4. The ordinate points on the x and y axis indicated the air temperature and humidity ratio, respectively. The enthalpy was explained as a slant axis on a psychrometric chart. After the dehumidification process by the thermoelectric and composite desiccant unit, the outdoor air (OA) was drawn into form the supply air (SA) that had a lower enthalpy. The return air (RA), once it passed the module, became the exhaust air (EA) once the temperature increased via the hot side of thermoelectric module and dehumidifier unit. The enthalpy, known as the energy state of air, was calculated using in (1).

$$h = c_{pa}T + \omega(c_{pw}T + h_g) \quad (1)$$

Whereby the temperature $T$ is calculated as ◦C; enthalpy $h$ at kJ/kg; $\omega$ is the humidity ratio (kg vapor/kg dry air); and $h_g$ is the water vapor enthalpy at 0 ◦C, while $c_{pa}$ and $c_{pw}$ are the specific heats of dry air and water vapor, respectively.

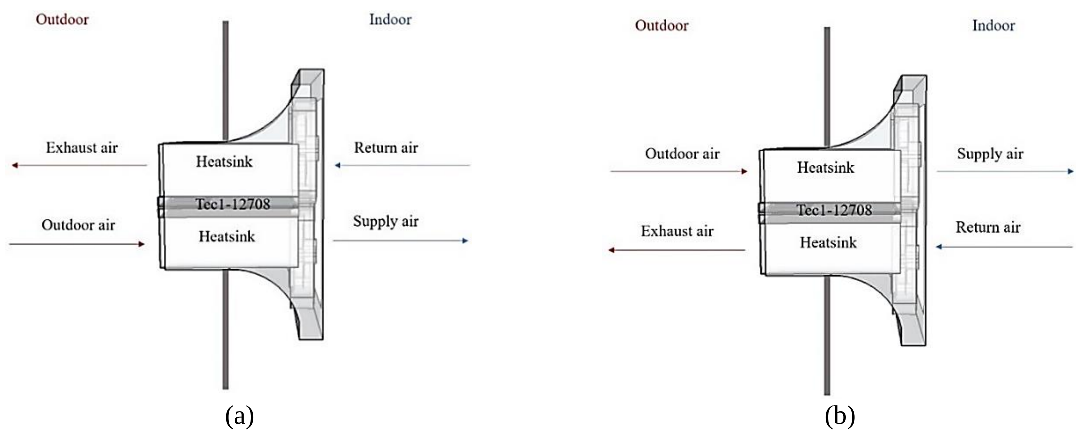


Figure 3. The operation of specially designed air ventilation system (a) dehumidification process and (b) switching mode for the regeneration process

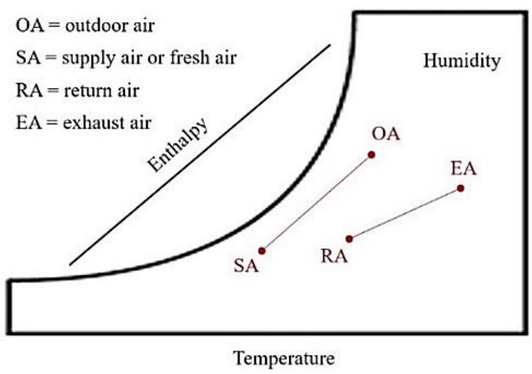


Figure 4. The psychrometric chart of specially designed air ventilation process

### 2.3. Monitoring control of special air ventilation system

A flowchart of the special air ventilation monitoring control is presented in Figure 5. The system was controlled according to standards set by the user or under ASHRAE 62.2 guidelines. The working mode of this system was divided in two modes: a dehumidification and a regeneration process. In the dehumidification process, the outdoor air was transported indoors by a DC fan. Afterwards, it was dehumidified by composite desiccant unit on the cold side of thermoelectric. Regarding the regeneration process, the composite desiccant coating on the heat sinks were used to absorb the heat on the by hot side of the TE, and the excessive heat convection was distributed into the outdoor environment. When the desiccants attain full energy capacity, the system switches mode to regenerate the saturated desiccants. These processes operated simultaneously and switched mode until the room reached a comfortable ambience as prescribed by the user. Furthermore, the data was displayed via a web application, and data was uploaded to a cloud storage database, where users can monitor, analyze, and download data in the form of comma-separated value files from the things peak server platform.

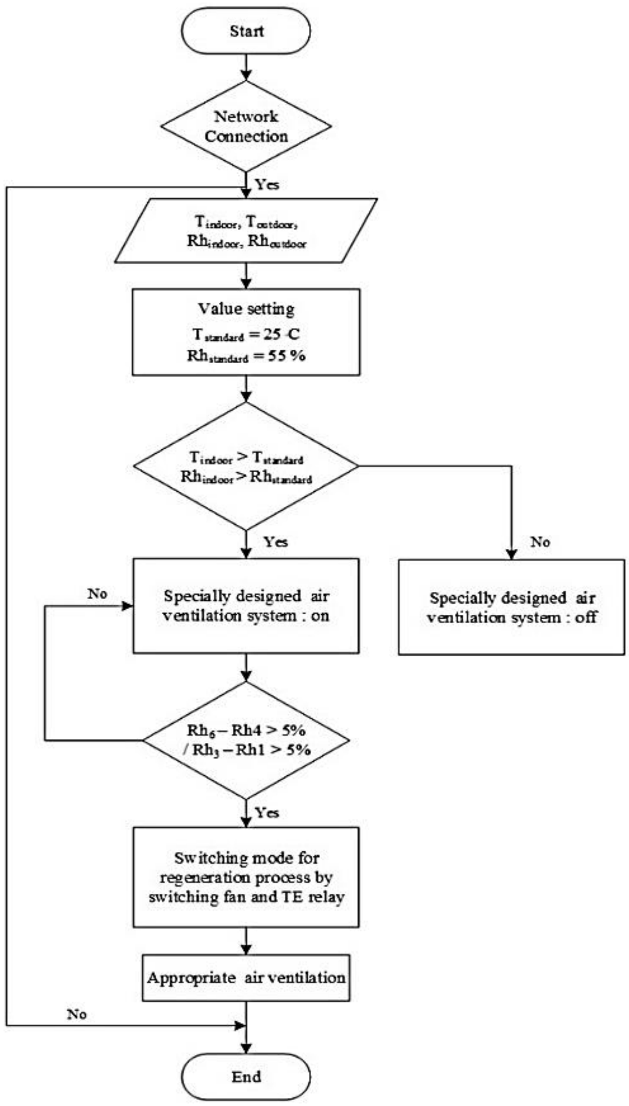


Figure 5. Flowchart of specially designed air ventilation monitoring control

### 2.4. Experimental setup

Figure 6 demonstrates the system configuration of this study. This arrangement was set to evaluate and optimize the indoor environmental factors such as temperature, humidity, and $CO_2$ level. The special ventilation unit was designed to operate in a scope that allowed the procedure to evaluate the performance and efficiency of the system for a period of 30 days, January 10, 2022 to February 9, 2022. The outdoor temperature and humidity during the experiment ranges from 25 ˚C to 35 ˚C and from 67% to 75%, respectively. The thermoelectric modules were supplied with electrical voltage at 3, 6, 9, and 12 V, producing the maximum temperature of the hot sides, 45 ˚C and cold sides, 19 ˚C. The indoor temperature, humidity, including the $CO_2$ level are controlled to the thermal comfort zone, which was dependent on the ASHRAE 62.2 [24] and indoor air quality standards.

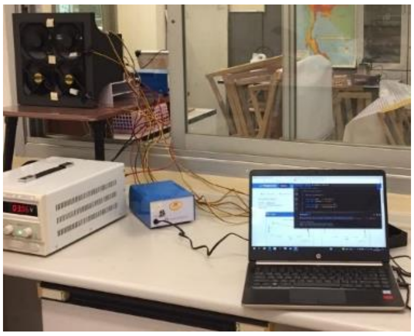

Figure 6. The configuration of specially designed air ventilation system

## 3. RESULTS AND DISCUSSION

This specially designed air ventilation system was separated into four sub sections: the optimization for indoor environmental improvement; the COP of the specially designed air ventilation system; the regeneration of composite desiccants; and the dehumidification process.

### 3.1. The optimization for indoor environmental improvement

Table 3 and Table 4 show the temperature and humidity improvements of the air when the system was operated under different conditions as a different power source was supplied to the TE module, while the fan speed was fix at 12 V. The result shows that the 12 V electrical supply to the thermoelectric module improved the air inlet to a thermal comfortability and indoor air ambience was in line with the national quality standards. The temperature of the outdoor showed a decrease of approximate 3 ˚C from the supply air of the TE module. Furthermore, the highest humidity reduction in the supply air was approximately 55% compared to the outdoor air. However, the temperature of exhaust air increased by hot side of the module due to the heat transfer between both sides of thermoelectric module. The average of indoor humidity and temperature of the supply air was approximately 55% and 27 ˚C, respectively when the ventilation system was operated at 12 V for 12 hours as shown in Figure 7. Additionally, the different power supply to TE module constantly maintained the $CO_2$ level at lower than 1000 ppm. However, 12 V of electrical voltage provided the minimum $CO_2$ level, which was approximately 650 ppm compared to the 800 ppm of $CO_2$ without system attached to the building structure as shown in Figure 8.

Table 3. The temperature improvement of air at different electrical voltage

| Input electrical voltage | Temperature (◦C) | | | |
|---|---|---|---|---|
| | OA (T4) | SA (T6) | RA (T3) | EA(T1) |
| 3 | 33.4 | 31.9 | 32.2 | 33.0 |
| 6 | 31.6 | 29.5 | 30.4 | 32.3 |
| 9 | 30.5 | 27.9 | 28.4 | 31.1 |
| 12 | 30.9 | 27.7 | 28.3 | 31.5 |

Table 4. The humidity improvement of air at different electrical voltage

| Input electrical voltage | Humidity (%) | | | |
|---|---|---|---|---|
| | OA (Rh4) | SA (Rh6) | RA (Rh3) | EA (Rh1) |
| 3 | 71.5 | 63.1 | 63.5 | 55.1 |
| 6 | 70.8 | 61.8 | 62.0 | 53.4 |
| 9 | 70.1 | 56.1 | 57.8 | 50.5 |
| 12 | 69.9 | 54.9 | 56.3 | 51.7 |

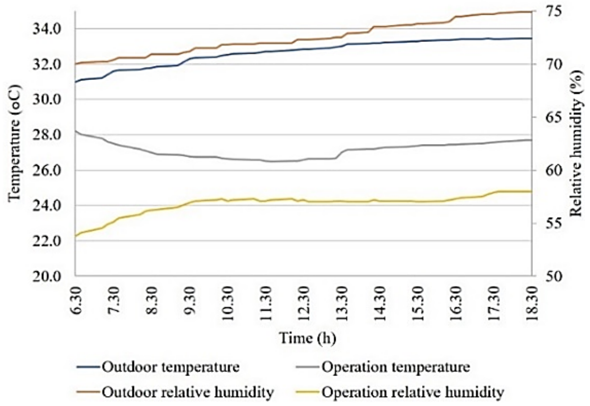


Figure 7. Operation relative humidity and temperature controlled by the specially designed air ventilation system at 12 V

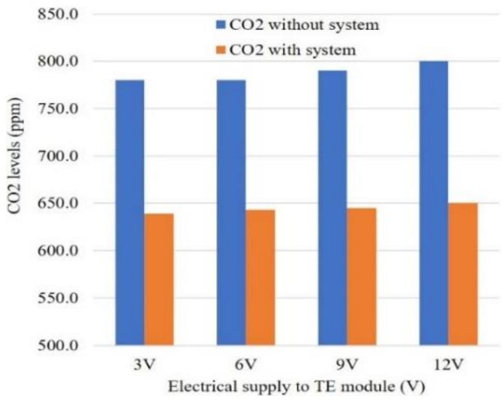


Figure 8. Comparison of $CO_2$ reduction of the specially designed air ventilation system

### 3.2. COP of special air ventilation system

Generally, the COP measurement is based on the output compared to input of the system. Consequently, the COP of this proposed system is a ratio of energy consumption of thermoelectric module and amount of heat removal for air cooling production as defined in (2)-(4) [25], [26].

$$Q_c = C_p m_{air}(\Delta t) \quad (2)$$

Where $Q_c$ is the amount of heat removal (J); $C_p$ is the specific heat capacity (J/kg◦C); $m_{air}$ is the air mass (kg); and $\Delta t$ is the temperature change between the cold and hot sides of thermoelectric module (◦C).

$$COP_{te} = \frac{Q_c}{Q_{in}+W_{te}} \quad (3)$$

Where $Q_c$ is the amount of heat removal; $Q_{in}$ is the heat absorbed from an ambience by a TE module; $W_{te}$ is the electrical supplying to TE module; and $W_{fan}$ is the electrical supply for DC fan.

$$COP_{system} = \frac{Q_{out}}{Q_{in}+W_{te}+W_{fan}} \quad (4)$$

The COP of this specially designed air ventilation system was calibrated, the output was then calculated at 3, 6, 9, and 12 V of electricity. The 12 V electrical supply to the TE modules provided the most COP for the system. However, the 9 V of electrical supply was suitable to save energy, and significantly improve the indoor thermal comfort and air quality more than a 12 V source.

### 3.3. Dehumidification performance

The dehumidification capacity was used to analyze the dehumidification performance in dehumidification process and was calculated using in (5). Where $Q_{de}$ is the dehumidification capacity (kg $h^{-1}$); $m_a$ is the mass flow rate of air (kg $s^{-1}$); $w_{ai}$ and $w_{ao}$ are the humidity ratio of outdoor air and supply air (g $kg^{-1}$); and $t_{de}$ is the dehumidification processing period (s). After testing at 3, 6, 9, and 12 V, the electrical supplying to the TE, the $Q_{de}$ of the special air ventilation system increased from 0.062 kg $h^{-1}$ at 3 V to 0.069 kg $h^{-1}$ at 6 V, and it was able to reach a maximum of 0.117 kg $h^{-1}$ at 9 V as shown in Figure 9. However, the $Q_{de}$ of the system at 12 V of electrical voltage slightly decreased from 0.117 kg $h^{-1}$ to 0.110 kg $h^{-1}$. Therefore, it was determined the 9 V electrical supply level to control the thermoelectric module was the optimum intensity regarding the dehumidification performance in this process.

$$Q_{de} = m_a \int_0^{t_{de}} (w_{ai} - w_{ao})\, dt)/t_{de} \quad (5)$$

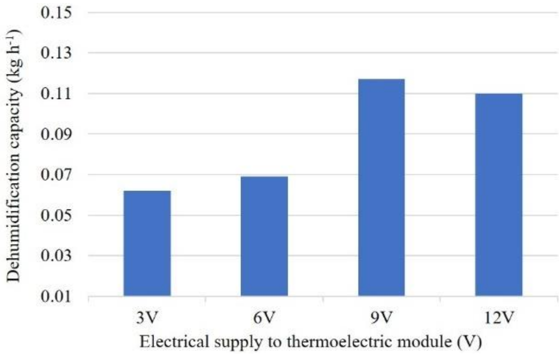


Figure 9. Dehumidification capacity of specially designed air ventilation system

### 3.4. Regeneration of composite desiccant

Whenever the dehumidifier unit is saturated, the specially designed air ventilation system switches to the regeneration mode. The increasing of air temperature through hot side of thermoelectric was used to recover the composite desiccant. The efficiency of the humidity removal of the composite dessicant unit was calculated using in (6).

$$\eta = \frac{Rh_{bf} - Rh_{af}}{Rh_{bf}} x\ 100 \quad (6)$$

Where by $\eta$ is the efficiency of moisture reduction of the composite desiccant, $Rh_{bf}$ and $Rh_{af}$ represent the relative humidity of before and after the system has performed. The average moisture removal during the regeneration process of the specially designed air ventilation system was shown in Figure 10. The composite desiccant unit of the system was used to absorb the moisture from the air then regenerate that moisture back to the outside air (the drying process) by 45 °C of hot side temperature of thermoelectric module, while using a 12 V of electrical supply source for 120 minutes.

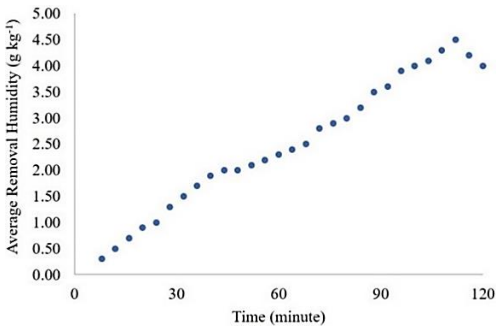


Figure 10. Average removal humidity of specially designed air ventilation system

## 4. CONCLUSION

This study focused on the development and optimization of a specially designed air ventilation system. The proposed system was designed to improve indoor environments using an integrated thermoelectric and composite desiccant unit. The monitoring controls were used to detect and control indoor factors such as temperature, humidity, and $CO_2$ concentration. A 12 V of electrical supply to thermoelectric provided optimal control of the temperature and humidity. Furthermore, the devices contained functions that limited the $CO_2$ emissions to 1000 ppm, while ensuring indoor air quality standard remain high, while providing thermal comfortability to occupants. An additional note was that a 12 V of electrical voltage also provided the highest COP of the system. However, this system's limitations are that it is not an optimal choice when consider energy a pathway more economical saving system. It is however an alternative approach for researchers to study further and industries to consider regarding energy savings and conventional air ventilation replacements.

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## REFERENCES

[1] P. Wargocki *et al.*, "Ventilation and Health in Non-industrial Indoor Environments: Report from a European Multidisciplinary Scientific Consensus Meeting (EUROVEN)," *Indoor air*, vol. 12, pp. 113–128, Jun. 2002, doi: 10.1034/j.1600-0668.2002.01145.x.

[2] J.M. Daisey, W.J. Angell, and M.G. Apte, "Indoor air quality, ventilation and health symptoms in schools: An analysis of existing information," *Indoor air*, vol. 13, pp. 53-64, Mar. 2003, doi: 10.1034/j.1600-0668.2003.00153.x.

[3] Seong-Yong Cheon *et al*., "Energy-saving potential of dedicated outdoor-air system assisted by vacuum-based membrane dehumidifier," *E3S Web Conferences*, vol. 111, Aug. 2019, doi: 10.1051/e3sconf/201911101087.

[4] I. Ibnu Hakim, R. Sukarno, and N. Putra, "Utilization of U-shaped finned heat pipe heat exchanger in energy-efficient HVAC systems," *Thermal Science and. Engineering Progress*, vol. 25, Oct. 2021, doi: 10.1016/j.tsep.2021.100984.

[5] M.-H. Kim, J.-E. Son, J. Heo, D. Kim, and D.-W. Lee, "Energy saving potential of an independent dedicated outdoor air system integrated with thermal energy storage for a childcare center," *Applied Thermal Engineering*, vol. 152, pp. 377–390, Apr. 2019, doi: 10.1016/j.applthermaleng.2019.02.084.

[6] L. Chen, Y. Chu, and W. Deng, "Experimental investigation of dedicated desiccant wheel outdoor air cooling systems for nearly zero energy buildings," *International Journal of Refrigeration*, vol. 134, pp. 265-277, Feb. 2022, doi: 10.1016/j.ijrefrig.2021.11.016.

[7] M. Su, X. Han, D. Chong, J. Wang, J. Liu, and J. Yan, "Experimental study on the performance of an improved dehumidification system integrated with precooling and recirculated regenerative rotary desiccant wheel," *Applied Thermal Engineering*, vol. 199, Nov. 2021, doi: 10.1016/j.applthermaleng.2021.117608.

[8] Y. Khan, G. Singh, J. Mathur, M. Bhandari, and P. Srivastava, "Performance assessment of radiant cooling system integrated with desiccant assisted DOAS with solar regeneration," *Applied Thermal Engineering*, vol. 124, pp. 1075–1082, Sep. 2017, doi: 10.1016/j.applthermaleng.2017.06.052.

[9] S. Tian, X. Su, H. Li, and Y. Huang, "Using a coupled heat pump desiccant wheel system to improve indoor humidity environment of nZEB in Shanghai: Analysis and optimization," *Building Environment*, vol. 206, Dec. 2021, doi: 10.1016/j.buildenv.2021.108391.

[10] D. Pandelidis *et al.*, "Performance analysis of rotary indirect evaporative air coolers," *Energy Conversion and Management*, vol. 244, Sep. 2021, doi: 10.1016/j.enconman.2021.114514.

[11] A. Shahsavar, S. Khanmohammadi, M. Khaki, and M. Salmanzadeh, "Performance assessment of an innovative exhaust air energy recovery system based on the PV/T-assisted thermal wheel," *Energy*, vol. 162, pp. 682-696, Nov. 2018, doi: 10.1016/j.energy.2018.08.044.

[12] Y. Men, X. Liu, and T. Zhang, "Experimental and numerical analysis on heat and moisture recovery performance of enthalpy wheel with condensation," *Energy Conversion and Management*, vol. 246, Oct. 2021, doi: 10.1016/j.enconman.2021.114683.

[13] H. M .D. P. Herath, M. D. A. Wickramasinghe, A. M. C. K. Polgolla, A. S. Jayasena, R. A. C. P. Ranasinghe, and M. A. Wijewardane, "Applicability of rotary thermal wheels to hot and humid climates," *Energy Rep.*, vol. 6, pp. 539-544, Feb. 2020, doi: 10.1016/j.egyr.2019.11.116.

[14] A. Shahsavar and S. Khanmohammadi, "Feasibility of a hybrid BIPV/T and thermal wheel system for exhaust air heat recovery: Energy and exergy assessment and multi-objective optimization," *Applied Thermal Engineering*, vol. 146, pp. 104–122, Jan. 2019, doi: 10.1016/j.applthermaleng.2018.09.101.

[15] H. Fu, X. Liu, Y. Xie, and Y. Jiang, "Experimental and numerical analysis on total heat recovery performance of an enthalpy wheel under high temperature high humidity working conditions," *Applied Thermal Engineering*, vol. 146, pp. 482-494, Jan. 2019, doi: 10.1016/j.applthermaleng.2018.10.026.

[16] J. Chaisan, S. Maneewan, and C. Punlek, "The Optimization of Hybrid Air Ventilation System Combined with Silica Gel and Thermoelectric Using Monitoring Control," *International Journal of Power Electronics and Drive System*, vol. 9, pp. 1624–1633, Dec. 2018, doi: 10.11591/ijpeds.v9.i4.pp1624-1633.

[17] K. Mihara, B. Lasternas, Y. Takemasa, K.W. Tham, and C. Sekhar, "Indoor environment evaluation of a Dedicated Outdoor Air System with ceiling fans in the tropics-A thermal manikin study," *Building Environment*, vol. 143, pp. 605-617, Oct. 2018, doi: 10.1016/j.buildenv.2018.07.048.

[18] K. Mihara, C. Sekhar, Y. Takemasa, B. Lasternas, and K.W. Tham, "Thermal comfort and energy performance of a dedicated outdoor air system with ceiling fans in hot and humid climate," *Energy and Buildings*, vol. 203, Nov. 2019, doi: 10.1016/j.enbuild.2019.109448.

[19] K. Mihara, C. Sekhar, Y. Takemasa, B. Lasternas, and K.W. Tham, "Thermal and perceived air quality responses between a dedicated outdoor air system with ceiling fans and conventional air-conditioning system," *Building. Environment*, vol. 190, Mar. 2021, doi: 10.1016/j.buildenv.2020.107574.

[20] S. Yang *et al.*, "Experimental study of model predictive control for an air-conditioning system with dedicated outdoor air system," *Applied Energy*, vol. 257, Jan. 2020, doi: 10.1016/j.apenergy.2019.113920

[21] T. Chen and L. Norford, "Energy performance of next-generation dedicated outdoor air cooling systems in low-energy building operations," *Energy Buildings*, vol. 209, Feb. 2020, Art. no. 109677, doi: 10.1016/j.enbuild.2019.109677

[22] C. Channoy, S. Maneewan, S. Chirarattananon, and C. Punlek, "Development and Characterization of Composite Desiccant Impregnated with LiCl for Thermoelectric Dehumidifier (TED)," *Energies*, vol. 15, no. 5, Feb. 2022, doi: 10.3390/en15051778.

[23] "Specification of TE Modules," Available from: https://hong-lang.en.alibaba.com. Accessed 4 January 2022.

[24] ASHRAE, "ANSI/ASHRAE 62.1&62.2 standards for ventilation and indoor air quality," ASHRAE.

[25] D. Song, T. Kim, S. Song, S. Hwang, and S.-B Leigh, "Performance evaluation of radiant floor cooling system integrated with dehumidified ventilation," *Applied Thermal Engineering,* vol. 8, pp. 1299-1311, Aug. 2008, doi: 10.1016/j.applthermaleng.2007.10.020.

[26] H.M. Künzel, A. Holm, D. Zirkelbach, and A.N. Karagiozis, "Simulation of indoor temperature and humidity conditions Including hygrothermal interaction with the building envelope," *Solar Engery*, vol. 78, pp. 554-561, Apr. 2005, doi: 10.1016/j.solener.2004.03.002.

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