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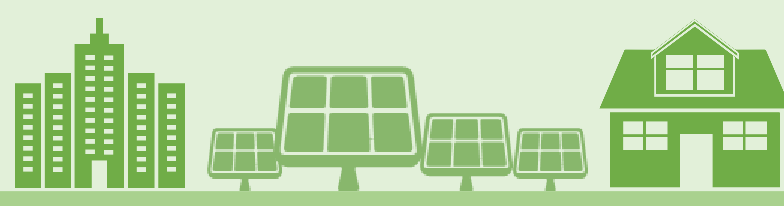

Thermal Performance of Wastewater Recovery from Air Conditioning for Cannabis Production

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Abstract

This research presents thermal simulation of selection working fluids of air conditioning from R-32, R-2452b, and R-466 for cannabis process. R-32 is a suitable working fluid in terms of a lowest mass of refrigerant of 0.65, a lowest mass of refrigerant per unit heat output of 0.0037, and a highest thermal COP of 7.53. The testing data from a Daikin R-32 air conditioning model of 12,300 BTU/h also shows that the simulation results are nearly with the experimental data in terms of a COP of 6.94 and a condensed wastewater of 18.302 litre/day. A cannabis lighting set is designed at a sizing of 1.0 m × 1.0 m × 1.8 m, one-violet LED of 300 W_e, and two-daylight LEDs at each of 100 W_e. A plant watering system is developed from Arduino board, solenoid valve, selector switch, LCD monitor, and drip emitter.

Keywords: Wastewater recovery; Air conditioning; Cannabis production; Thermal simulation

Introduction

Cannabis and smart farming topics are a popular topic in the present medication in Thailand. Internet of things (IOT) is implemented to enhance cannabis cultivation such as temperature, humidity, lighting, and etc. Cannabis is highly promoted for medical products to cure cancer, Alzheimer's disease, and etc. Indoor and outdoor techniques are several discussed for cannabis cultivation. The advantage of outdoor method is low cost, while the main point of indoor method is controllable conditions. The indoor and outdoor cultivation methods are presented in the various research works of design, simulation, construction, and technology. Vanhove et al. [1], Zhang et al. [2], Niam et al. [3], Lim and Kim [4], and Yongson et al. [5] presented a computational fluid dynamics (CFD) technique to design the optimal temperature, relative humidity, air velocity, air flow pattern, and pressure drop for indoor planting room. The CFD was also used to evaluate the suitable conditions for reducing the crop period, investment cost, and operating cost from indoor plant cultivation. In addition, Chaiyat and Kiatsiriroat [6] presented a thermodynamic simulation for selection the suitable working fluid in heat pump and air conditioning. R-290, R-123, R-32, and R-410a were used to contain in both heat engines. This work was supported by Taira et al. [7] and Dalkilic and Wongwises [8], which also represented a new type working fluid by using mixed refrigerants in heat pump and air conditioning.

From the above study works, thermal simulation was the popular technique to investigate the obtimal condition in air conditioning system, heat pump system, and air ventilation for the closed system.

The objective of this study aims to:

1. Evaluate the optimal conditions for cannabis cultivation by using thermal simulation technique.
2. Design a cannabis lighting set for cannabis production.
3. Develop an automatic plant watering system from wastewater of air conditioning.

Conceptual framework

Figure 1 shows schematic diagram of an integrated system of air conditioning cycle, wastewater recovery system, and plant watering system. Cooling load (Q_E) from the closed system (indoor room) releases heat into an evaporator at a fan coil unit of air conditioning. A low boiling temperature refrigerant absorbs heat from moist air. After that, refrigerant at the mixture phase transfers to be the pure vapor, which is increased enthalpy, pressure, and temperature by a compressor (W_{Comp}). Then, the high-energy fluid is rejected heat to the environment by a condenser (Q_C) at a condensing unit of air conditioning. The vapor phase is condensed to be the liquid phase, and sent through an expansion value for decreasing pressure in form of the mixture fluid. At the evaporator, a condensed wastewater from the moist air is kept in a wastewater tank for cannabis process. Cooling efficiency in terms of a coefficient of performance (COP) can be defined as follows:

$$COP_{AC} = \frac{Q_E}{W_{Comp}}, \quad (1)$$

$$Q_E = \dot{m}_{da,E}(h_{a,E,i} - h_{a,E,o}) - \dot{m}_W h_{fg,W}, \quad (2)$$

$$\dot{m}_W = \dot{m}_{da,E}(\omega_{a,E,i} - \omega_{a,E,o}). \quad (3)$$

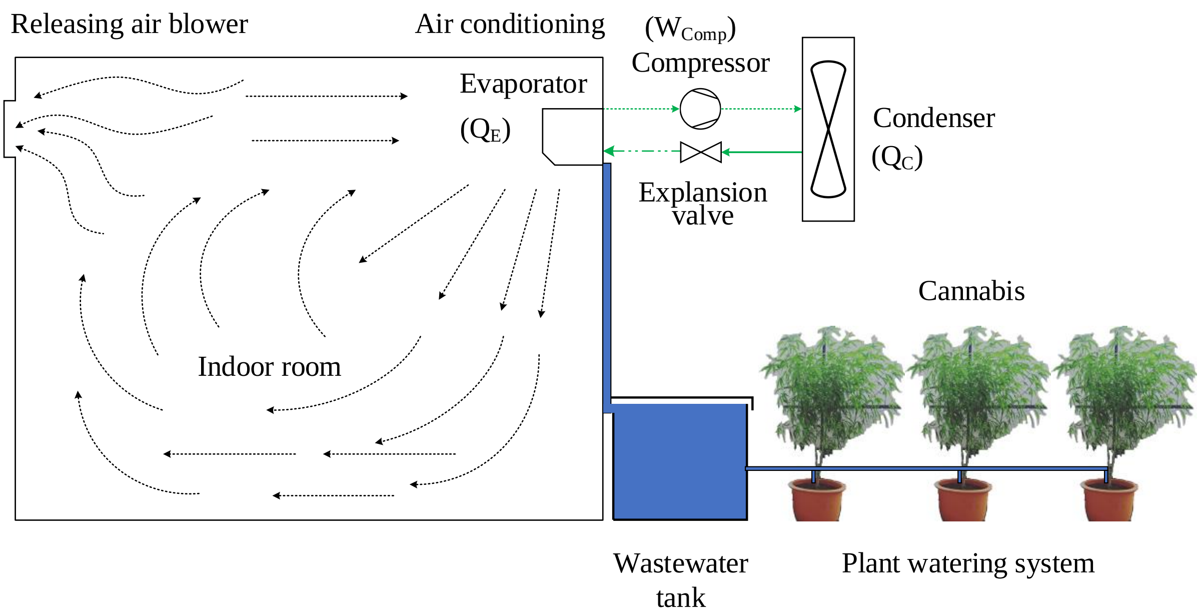

Figure 1 A schematic diagram of wastewater recovery system from air conditioning.

Methods and apparatus

The methods and apparatus of this study are as follows:

1. The suitable working fluid of air conditioning is investigated by using a first law of thermodynamic simulation. Three new environmental refrigerants of R-32, R-2452b, and R-466 are selected in this study, which are focused on an Ozone Depletion Potential impact, as shown in Table 1.

Table 1: The properties of 3 type working fluids.

Descriptions	R-32[1]	R-452b[2]	R-466a[3]
Molecular mass (kg/kmol)	52.03	63.5	80.7
Critical temperature (°C)	78.11	77.1	83.8
Critical pressure (MPa)	5.78	5.22	5.91
Boiling point temperature (°C)	-51.65	-51.0	-51.7
Safety group[4]	A2	A2	A1
Ozone Depletion Potential (ODP, R11-ralated)	0	0	0
Global warming potential (GWP, CO_2-100 y)	675	698	733

Remark: [1] ASHRAE (2009) [9].

[2] Honeywell (2020) [10].

[3] Atilla and Vedat (2020) [11].

[4] A1 is nontoxicity and no flammability, A2 is nontoxicity and lower flammability.

2. The thermal simulation result is implemented the indoor room to verify the simulation and testing data. The COP and condensed wastewater from air conditioning values are investigated and compared between the simulation and testing data under the controlled conditions at a room temperature of 25 °C and a relative humidity of 50-55%.

3. The cannabis lighting set for cannabis process is developed from the comparison results. Daylight and violet light emitting diodes (LED) are used to implement the lighting set. In addition, the wavelength, spectral irradiance, and photosynthetic photon flux density (PPFD) parameters are measured by a PG100N handheld spectral PAR meter.

4. The plant watering system is also designed and constructed from the verified data to support the nursery, vegetative, and flowering stages.

Results and discussion

1. Thermal simulation

Four thermal indicators of mass of refrigerant, mass of refrigerant per unit heat output, carbon dioxide emission per mass of refrigerant, and COP are used to select the suitable working fluid in this study.

Table 2 shows comparison of the thermal simulation results under the control conditions of a room temperature of 25 °C, humidity ratio of the inlet and outlet air from evaporator of 55% and 50%, respectively. R-32 reveals the advantage points in terms of a lowest mass of refrigerant of 0.65, a lowest mass of refrigerant per unit heat output of 0.0037, and a highest thermal COP of 7.53. From the above data, R-32 shows a low value of working fluid, which directly effects to the working fluid cost and power consumption of compressor. In addition, R-32 can save the operating cost under a same cooling capacity of 3.517 kW. While, R-452b shows a best environmental impact of 5.22 kg CO_2/kg_{ref}. Thus, the suitable working fluid in air conditioning from the simulation results is R-32.

Table 2: The properties of 3 type working fluids.

Thermal value	R-32	R-452b	R-466a
Mass of refrigerant (kg)	0.65	0.68	0.79
Mass of refrigerant per cooling capacity (kg/kJ)	0.0037	0.0044	0.0064
CO_2 emission per mass of refrigerant (kg CO_2/kg_{ref})	5.78	5.22	5.91
COP (-)	7.53	7.21	6.56

2. Comparison results of thermal simulation and testing data

A Daikin commercial R-32 air conditioning model of 12,300 BTU/h (a fan coil unit model of FTKQ12SV2S and a condensing unit model of RKQ12SV2S) is chosen for experimental process in an insulator room at a sizing of width 2.4 m × long 3.4 m × high 2.5 m, as show in Figure 2. The comparison results found that the real performance of COP is 6.94, which is lower than that of the simulation result of approximately 5.71%. In addition, the condensed wastewater from R-32 air conditioning is found approximately 18.302 litre/day, which is slightly with a simulation result of 18.742 litre/day. The wastewater recovery value of approximately 18 litre/day is used to design the plant watering system in the next part.

The different values of COP and condensed water of the comparison results are occurred from the uncontrolled cooling load of cannabis room. In the simulation, the cooling load can be fixed to be 3.517 kW. On the other hand, the real testing process cannot control the cooling load as steady state.

3.Cannabis lighting set

The cannabis lighting set at a sizing of approximately 1.0 m × 1.0 m × 1.8 m is designed for four cannabis pots at each volume of approximately 12 L. One-violet LED at a power of 300 W_e and two-daylight LEDs at each power of 100 W_e are selected for generating a wavelength of approximately 600 nm, a spectral irradiance of approximately 200 $mW/m^2 \cdot nm$, and a PPFD of approximately 100 $\mu mol/m^2 \cdot s$, as shown in Figure 3. The violet LED can adjust the high level following the sizing of cannabis.

The measurement data indicates that the lighting set should be enhanced all light intensity parameters, especially violet LED. The spectral irradiance of all lighting area should be increased to be 200 $mW/m^2 \cdot nm$.

Figure 2: A photograph of indoor room and air conditioning system.

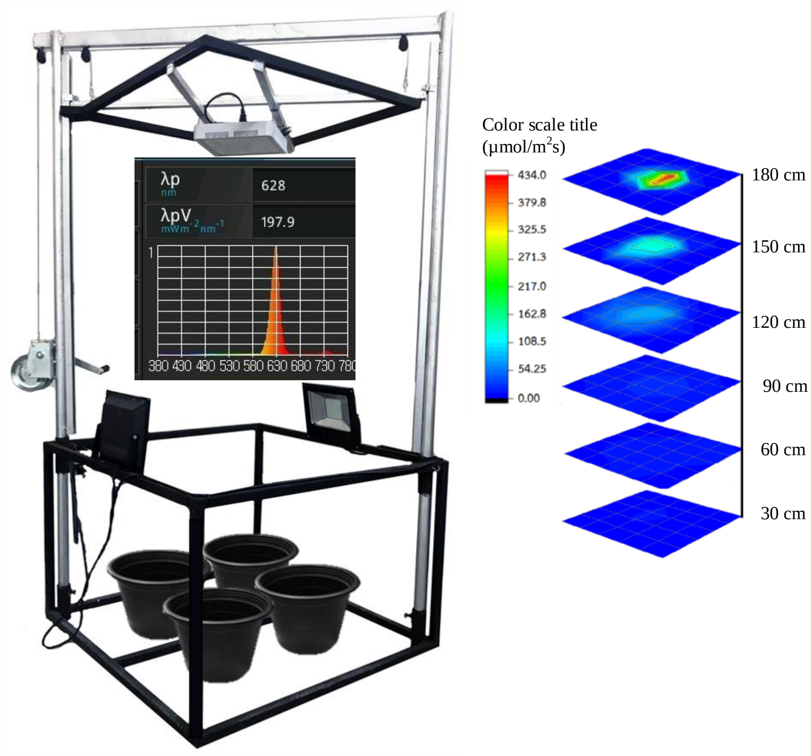

Figure 3: A prototype cannabis lighting set.

4. Wastewater recovery of air conditioning

From the thermal simulation, wastewater from the 12,300 BTU/h air conditioning at approximately 18 L/day can supply for 20 plants and 5 cannabis lighting sets. Thus, the plant watering system is designed for three modes of 24 h, 48 h, and 72 h. The control devices of Arduino board, solenoid valve, selector switch, LCD monitor, and drip emitter are used to develop the plant watering system, as shown in Figure 4.

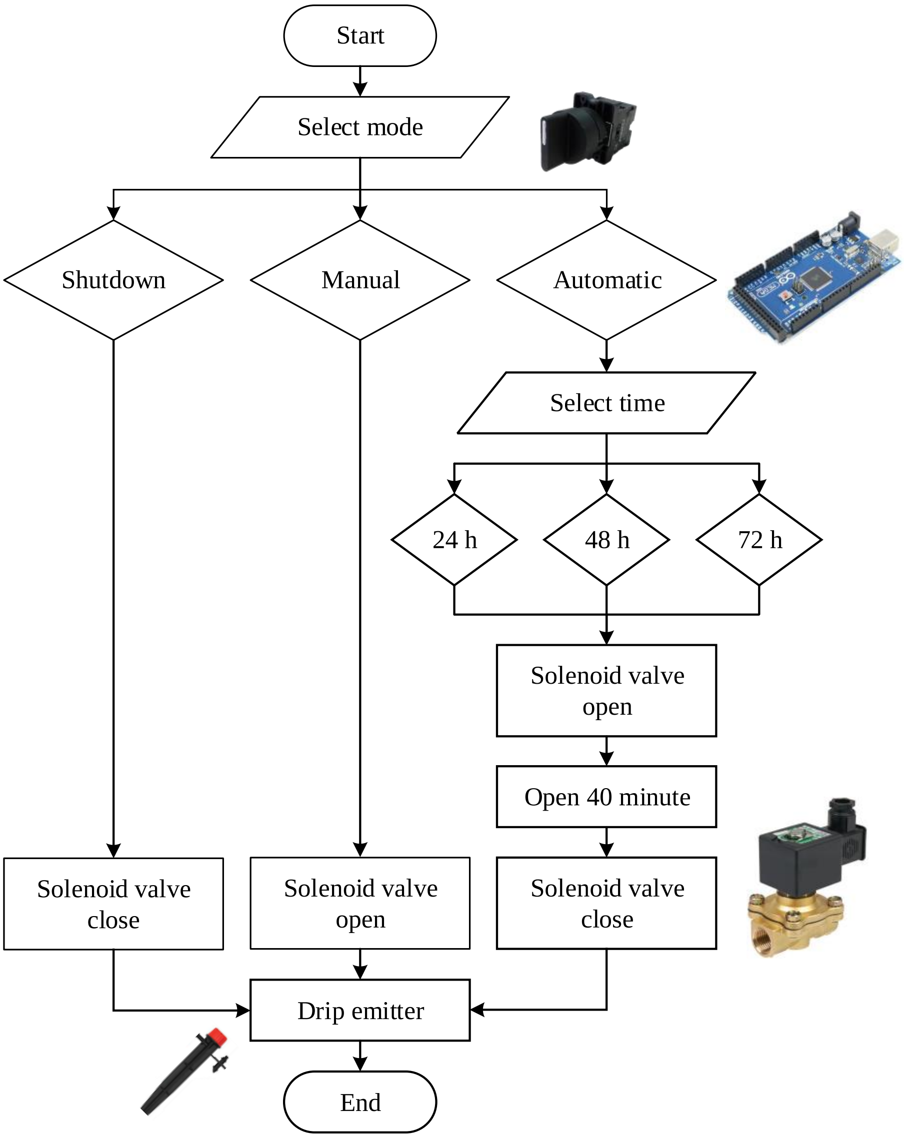

Figure 4: A conceptual design of plant watering system.

From the testing process, the plant watering system is found the error point from electrical power outage. Timer system on microcontroller board is automatically reset, which directly effects to overall plant watering time. Thus, in the next version, timer system of the plant watering system is programmed from the online internet system.

Conclusions and recommendations

From the above study results, it can be concluded as follows:

- R-32 is the suitable working fluid of wastewater recovery system from air conditioning for cannabis production in terms of the low-mass of refrigerant, low-mass of refrigerant per unit heat output, and high-thermal COP.
- The testing data from the Daikin commercial R-32 air conditioning model of 12,300 BTU/h shows nearly with the simulation results in terms of the COP of 6.94 and the condensed wastewater of 18.302 litre/day.
- The cannabis lighting set is designed at the sizing of 1.0 m □ 1.0 m □ 1.8 m, one violet LED of 300 W_e, and 2-daylight LEDs at each of 100 W_e.
- The prototype of plant watering system is developed from Arduino board, solenoid valve, selector switch, LCD monitor, and drip emitter for three modes of 24 h, 48 h, and 72 h, respectively.

For the future study, the economic (levelized product cost) and environmental (life cycle assessment, LCA) impacts will be investigated and reported in the next work.

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Abbreviations and symbols

Nomenclature

EER	energy efficiency ratio, (kW_{th}/kW_e)
h	enthalpy, (kJ/kg)
M	mass, (kg)
$\dot{m}$	mass flow rate, (kg/s)
P	pressure, (bar)
Q	heat capacity, (kW)
T	temperature, (°C)
W	Power, (kW_e)

Abbreviations

AC	air conditioning

Greek

ω	humidity ratio, (kg_W/kg_{da})
Subscript	
a	moist air
C	condenser
Comp	compressor
da	dry air
e	electricity
E	evaporator
f	liquid fluid
g	vapor fluid
i	inlet
o	outlet
ref	refrigerant
th	thermal
W	water

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