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Examination of Energy Efficiency of Air Handling Unit with Integrated Air to Air Heat Exchanger in Cooling Mode

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Abstract: Object of the present study is an experimental determination of parameters, showing efficiency of air handling unit with integrated air to air heat exchanger in cooling mode: effectiveness of supply side of air to air heat exchanger, coefficient of performance and specific fan power of air handling unit. A daily performance of air handling unit in cooling mode is conducted. Effectiveness of supply side of air to air heat exchanger in range of 50.5 % to 74.3 % is received. Coefficient of performance in range of 0.88 to 2.99 and specific fan power of air handling unit in range of 1.77 kW/(m^3/s) to 3.06 kW/(m^3/s) are received. A relation between effectiveness of supply side of air to air heat exchanger and ratio of heat capacity rates of supply and exhaust air is received. Effectiveness of supply side of air to air heat exchanger depends on values of mass flow of supply and the exhaust air. High values of mass flow of exhaust air responds to high effectiveness of supply side of air to air heat exchanger.

Keywords: Air handling unit, air to air heat exchanger, effectiveness, coefficient of performance, specific fan power

Introduction

Air handling units are equipment used for air conditioning of large office and commercial buildings. These units need to provide cooling, heating and required amount of fresh air in conditioned space of the building. A necessary amount of supply fresh air must be with high purity and required temperature, so that it does not affect negative to the people in an air-conditioned room. To minimize energy costs, air handling units has an integrated air to air heat exchanger and heating (cooling) section with direct evaporation of refrigerant (heat pump). (Kolev et al, 2020). The initial heating (cooling) of supply air in air handling unit is realized by passing it through air to air exchangers, in which it accepts (takes away) heat with exhaust air, taken away from the room. The heat exchangers used in air handling unit can be different types - plate heat exchangers, rotary heat wheel or heat pipe. (Masitah et al., 2015). The main heating (cooling) of supply air is performed by heating (cooling) section of air handling units, where energy of supply air is delivered by electric power, hot or cold fluid. High energy efficiency of these units is guaranteed by use of efficiency heat exchangers, cooling and heating sections with low energy costs for air cooling and heating, as well as the use of fans with low electrical energy consumption. Energy efficiency of air handling units is based on the values of three parameters: effectiveness of air to air heat exchanger, coefficient of performance and specific electric fan power, consumed by fans of air handling unit.

Cross flow air to air plate heat exchangers have high efficiency in small sizes. Main advantages of aluminium plate heat exchangers are also: corrosion resistance, fire safety, no moisture and odor transfer between supply and exhaust air. Effectiveness of these heat exchanger can be calculated by supply side and exhaust side.

Energy efficiency class of heat pumps in air handling units is determined according to Delegated Regulation (EU) 626/2011, supplementing Directive 2010/30/EU with regard to energy labelling of air conditioners. Energy efficiency class of air handling units is determined according to Regulation (EU) 1253/2014, implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for ventilation units. High values of effectiveness of air to air heat exchanger and coefficient of performance of air handling unit and low values of specific electric fan power of air handling unit indicate high energy efficiency of the system. (Bobilov et al., 2011), (Kolev et al., 2017).

In this study a daily performance of air handling unit in cooling mode is conducted. Temperatures of supply air on outlet and inlet of air to air heat exchanger and temperature of exhaust air on inlet of air to air heat exchanger are measured. Room temperature, outdoor temperature and velocities of supply and exhaust air of air handling unit are measured and mass flow rates through heat exchanger are calculated. Heat capacity rates of the supply and exhaust air are determined. Effectiveness on a supply side of air to air heat exchanger is determined. Electrical power of refrigeration compressor, supply and exhaust fan of air handling unit are measured. Heat flux exchanged in cooling section, coefficient of performance in cooling section (heat pump) are calculated. Heat flux exchanged in air to air heat exchanger, total cooling capacity of air handling unit and coefficient of performance of air handling unit are calculated. Specific fan power of air handling unit is determined. A relation between effectiveness of supply side of air to air heat exchanger and ratio of heat capacity rates of the supply and exhaust air is received.

Materials and Methods

The installation is located in science laboratory of University Of Food Technology – Plovdiv, Bulgaria.
Schematic diagram of air handling unit is shown on Figure 1.

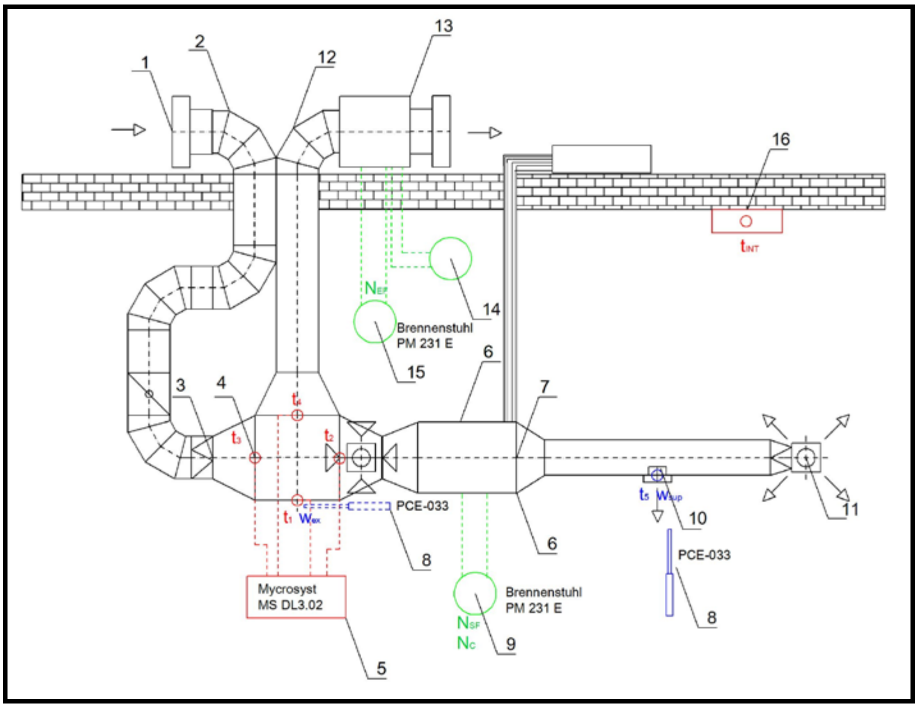

Figure1. Schematic diagram of air handling unit

Through external grill 1 supply air (100 % fresh air) goes to supply air duct 2. Supply fan 7 trasport supply air to conditioned room and enters the room from grills 10 and 11. The fan is mounted in cooling section of air handling unit (HP unit) 6. To air duct 2 supply air passes through filter section 3 and enters to air to air plate heat exchanger HE 4, where it is precooled by exhaust air from the room. The temperatures of supply air on inlet and outlet of HE 4 t_3 and t_2 is measured with temperature sensors, connected to controller 5. Precooled supply air from air to air plate heat exchanger HE 4 passes through HP unit 6, where is additionally cooled. The temperature of supply air on outlet of HP unit t_5 and his velocity w_{sup} are measured by thermo-anemometer 8. Energy power consumption of HP unit and supply fan are measured by digital wattmeter 9. The exhaust air is transported on exhaust air duct 12 by exhaust fan 13, mounted in ventilation box. Exhaust fan is equipped with fan speed controller 14. The temperatures of exhaust air on inlet and outlet of HE 4 t_1 and t_4 is measured with temperature sensors, connected to controller 5. The velocity of exhaust air on inlet of HE 4 w_{ex} is measured by thermo-anemometer 8. The energy power consumption of exhaust fan are measured by digital wattmeter 15.The temperature of air in the room t_{int} is measured with remote controller 16. General appearance of air handling unit are shown in Figure 2. (Valchev et al., 2019)

Figure 2. General appearance of air handling unit

Measuring devices and measured parameters of air handling unit are shown in Table 1.

Table 1. Measuring devices and measured parameters of air handling unit

Measuring device	Measured parameter	Designation	Precision measuring	Measuring range
Remote controller Fujitsu General UTY-RNNYM 1	Set point of room temperature	t_{int}, ºC	±1.0 ºC	10-30 ºC
Controller Mycrosyst Data Logger GSM Dialer MS DL3.02 – 2 – 4 channel	Air temperatures in control point of air handling unit	t_1,t_2,t_3,t_4 ºC	±0.1 ºC	10-60 ºC
Thermo-anemometer PCE-033	Air temperatures and velocities in control point of air handling unit	t_5,ºC w_{sup}, w_{ex}, m/s	Temperature: ±0.1 ºC Velocity: ±0.1 m/s	Temperature: 0.0-50 ºC Velocity: 0.2-20 m/s
Digital wattmeter Brennenstuhl PM 231 E	Current power consumption of electrical energy spent by refrigeration compressor and supply air fan;	N_{SF}, N_{C}, W	±0.2W	0-9999.9 kWh
Digital wattmeter Brennenstuhl PM 231 E	Current power consumption of electrical energy spent by exhaust air fan	N_{EF}, W	±0.2W	0-9999.9 kWh

Results and Discussion

A daily performance of air handling unit is conducted. The temperatures of supply air on outlet t_2 and inlet t_3 of air to air heat exchanger and temperature of exhaust air on inlet t_1 of air to air heat exchanger are measured three times for one hour. The velocities of supply air w_{sup} and exhaust air w_{ex} of air handling unit are measured three times for one hour. Respective arithmetical mean values of measured temperatures and velocities are calculated. Mass flow rates of supply air and exhaust air through heat exchanger are determined by equations:

$$\dot{m}_{sup} = \rho_{air}.w_{sup}.f_{sup}$$

$$\dot{m}_{ex} = \rho_{air}.w_{ex}.f_{ex}$$

where: - ρ_{air} – density of air for average temperature of air on inlet and outlet of air to air heat exchanger, kg/m^3;

w_{sup} – velocity of supply air on outlet of grill of rectangular duct, m/s;

w_{ex} – velocity of exhaust air on inlet of air to air heat exchanger, m/s;

f_{sup} – effective area of grill on rectangular duct, m^2.

f_{ex} – effective area of ait to air heat exchanger, m^2.

The results are shown in Table 2.

Table 2. Experimental data – Temperatures and mass flow rates heat exchanger

№	t_1 ˚C	t_2 ˚C	t_3 ˚C	t_5 ˚C	w_{sup} m/s	$\dot{m}_{sup}$ kg/s	w_{ex} m/s	$\dot{m}_{ex}$ kg/s
1	28.8	28.9	29.0	12.2	5.6	0.0869	0.3	0.0815
2	28.6	28.8	29.0	12.2	5.5	0.0853	0.3	0.0815
3	28.2	29.0	29.8	12.0	5.3	0.0822	0.3	0.0815
4	27.4	28.9	30.5	12.2	5.1	0.0791	0.3	0.0815
5	26.5	27.7	30.6	10.9	5.0	0.0776	0.4	0.1086
6	26.3	28.5	33.1	10.4	4.6	0.0714	0.4	0.1086
7	26.3	28.5	33.2	10.5	4.5	0.0698	0.4	0.1086
8	26.0	27.9	33.3	10.8	4.4	0.0683	0.5	0.1358
9	26.1	28.0	33.5	11.3	4.0	0.0621	0.5	0.1358
10	26.0	27.5	31.4	11.5	3.9	0.0605	0.5	0.1358

Heat capacity rate of the supply air C_s and heat capacity rate of the exhaust air C_e are determined by equations:

$$C_s = \dot{m}_{sup}.C_{air}$$

$$C_e = \dot{m}_{ex}.C_{air}$$

where: - $\dot{m}_{sup}$ – mass flow rate of supply air through the heat exchanger, kg/s;

$\dot{m}_{ex}$ - mass flow rate of exhaust air through the heat exchanger, kg/s;

C_{air} – specific heat capacity of the supply air, kJ/kg.K, (C_{air} =1,0 kJ/kg.K).

Effectiveness on a supply side of air to air heat exchanger ε_s is determined as follows (Larson & Pihlquist, 2011), (Pisarev et al., 2016):

$$\varepsilon_s = \frac{C_s}{C_{min}}.\left(\frac{t_2 - t_3}{t_1 - t_3}\right).100$$

where: - C_{min} – minimum of C_s and C_e, kW/K.

t_2 – temperature of supply air on outlet of air to air heat exchanger, ^oC;

t_3 – temperature of supply air on inlet of air to air heat exchanger, ^oC;

t_1 – temperature of exhaust air on inlet of air to air heat exchanger, ^oC.

t_4 – temperature of exhaust air on outlet of air to air heat exchanger, ^oC.

The results are shown in Table 3.

Table 3. Experimental data – Effectiveness supply side heat exchanger

№	$\dot{m}_{sup}$ kg/s	$\dot{m}_{ex}$ kg/s	C_s kW/K	C_e kW/K	C_s/C_e -	ε_s %
1	0.0869	0.0815	0.0869	0.0815	1.07	53.3
2	0.0853	0.0815	0.0853	0.0815	1.05	52.4
3	0.0822	0.0815	0.0822	0.0815	1.01	50.5
4	0.0791	0.0815	0.0791	0.0815	0.97	51.6
5	0.0776	0.1086	0.0776	0.1086	0.71	70.7
6	0.0714	0.1086	0.0714	0.1086	0.66	67.6
7	0.0698	0.1086	0.0698	0.1086	0.64	68.1
8	0.0683	0.1358	0.0683	0.1358	0.50	74.0
9	0.0621	0.1358	0.0621	0.1358	0.46	74.3
10	0.0605	0.1358	0.0605	0.1358	0.45	72.2

Heat flux exchanged in heat pump unit $\dot{Q}_{HP}$ and coefficient of performance in cooling section (heat pump unit) COP_{HP} are calculated by equations:

$$\dot{Q}_{HP} = \dot{m}_{sup} .C_{air} (t_2 - t_5)$$

where: - t_5 – temperature of supply air on outlet of heating section (HP unit), ^oC;

$$COP_{HP} = \frac{\dot{Q}_{HP}}{|N_C|}$$

where: - N_C – electrical power for refrigeration compressor of heat pump unit, W.

Electrical power of refrigeration compressor N_C is measured three times in one hour and respective arithmetical mean values of this power are calculated. The results are shown in Table 4.

Table 4. Experimental data – Coefficient of performance on heat pump unit

№	t_2 ˚C	t_5 ˚C	w_{sup} m/s	$\dot{m}_{sup}$ kg/s	$\dot{Q}_{HP}$ W	N_C W	COP_{HP} -
1	28.9	12.2	5.6	0.0869	1451	302	4.80
2	28.8	12.2	5.5	0.0853	1417	361	3.92
3	29.0	12.0	5.3	0.0822	1398	558	2.51
4	28.9	12.2	5.1	0.0791	1321	696	1.90
5	27.7	10.9	5.0	0.0776	1303	799	1.63
6	28.5	10.4	4.6	0.0714	1292	922	1.40
7	28.5	10.5	4.5	0.0698	1257	955	1.32
8	27.9	10.8	4.4	0.0683	1167	1088	1.07
9	28.0	11.3	4.0	0.0621	1036	1193	0.87
10	27.5	11.5	3.9	0.0605	968	1188	0.81

Heat flux exchanged in air to air heat exchanger $\dot{Q}_{HE}$, total cooling capacity of air handling unit $\dot{Q}_{AHU}$ and coefficient of performance of air handling unit COP_{AHU} are calculated by the equations (Michalak, 2021), (Zhou et al.,2018), (Gendebien et al., 2018):

$$\dot{Q}_{HE} = \dot{m}_{\sup} . C_{air} (t_3 - t_2)$$

$$\dot{Q}_{AHU} = \dot{Q}_{HP} + \dot{Q}_{HE}$$

$$COP_{AHU} = \frac{\dot{Q}_{AHU}}{|N_{TOT}|}$$

Total power consumption of air handling unit N_{TOT} is calculated by equation:

$$N_{TOT} = N_C + N_{SF} + N_{EF}$$

Power consumption of supply N_{SF} and exhaust fan of N_{EF} of air handling unit is measured three times in one hour and respective arithmetical mean values of this power are calculated. The results are shown in Table 5.

Table 5. Experimental data – Coefficient of performance of air handing unit

№	t_2	t_3	$\dot{m}_{\sup}$	$\dot{Q}_{HE}$	$\dot{Q}_{AHU}$	N_{TOT}	COP_{AHU}
	˚C	˚C	kg/s	W	W	W	-
1	28.9	29.0	0.0869	9	1460	489	2.99
2	28.8	29.0	0.0853	17	1434	548	2.62
3	29.0	29.8	0.0822	66	1464	751	1.95
4	28.9	30.5	0.0791	127	1448	876	1.65
5	27.7	30.6	0.0776	225	1528	980	1.56
6	28.5	33.1	0.0714	328	1620	1108	1.46
7	28.5	33.2	0.0698	328	1585	1144	1.39
8	27.9	33.3	0.0683	369	1536	1274	1.21
9	28.0	33.5	0.0621	341	1378	1381	1.00
10	27.5	31.4	0.0605	236	1204	1375	0.88

Specific fan power of air handling unit SFP, volume flow rate of exhaust air $\dot{V}_{ex}$ and total power consumption of supply and exhaust fan of air handling unit N_F are determined by equations:

$$SFP = \frac{N_F . \dot{\rho}_{air}}{\dot{m}_{MAX}},$$

where:- $\dot{m}_{MAX} = \dot{m}_{ex}$ – maximum mass flow rate throw air to air heat exchanger, equal to mass flow rate of exhaust air throw air to air heat exchanger, kg/s.

$$\dot{V}_{ex} = \frac{\dot{m}_{ex}}{\rho_{air}}$$

$$N_F = N_{SF} + N_{EF}$$

where: - N_{SF} – electrical power for supply fan of air handling unit, W;

N_{EF} – electrical power for exhaust fan of air handling unit, W.

The results are shown in Table 6.

Table 6. Experimental data – Specific fan power of air handling unit

№	$\dot{m}_{ex}$ kg/s	$\dot{V}_{ex}$ m^3/s	N_{SF} W	N_{EF} W	N_C W	N_{TOT} W	SFP kW/(m^3/s)
1	0.0815	0.0630	22	165	302	489	2.97
2	0.0815	0.0630	21	166	361	548	2.97
3	0.0815	0.0630	21	172	558	751	3.06
4	0.0815	0.0630	20	160	696	876	2.86
5	0.1086	0.0840	20	161	799	980	2.15
6	0.1086	0.0840	25	161	922	1108	2.21
7	0.1086	0.0840	24	165	955	1144	2.25
8	0.1358	0.1050	22	164	1088	1274	1.77
9	0.1358	0.1050	23	165	1193	1381	1.79
10	0.1358	0.1050	22	165	1188	1375	1.78

In Figure 3 a correlation between effectiveness of supply side of air to air heat exchanger and ratio of heat capacity rates of supply and exhaust air is shown.

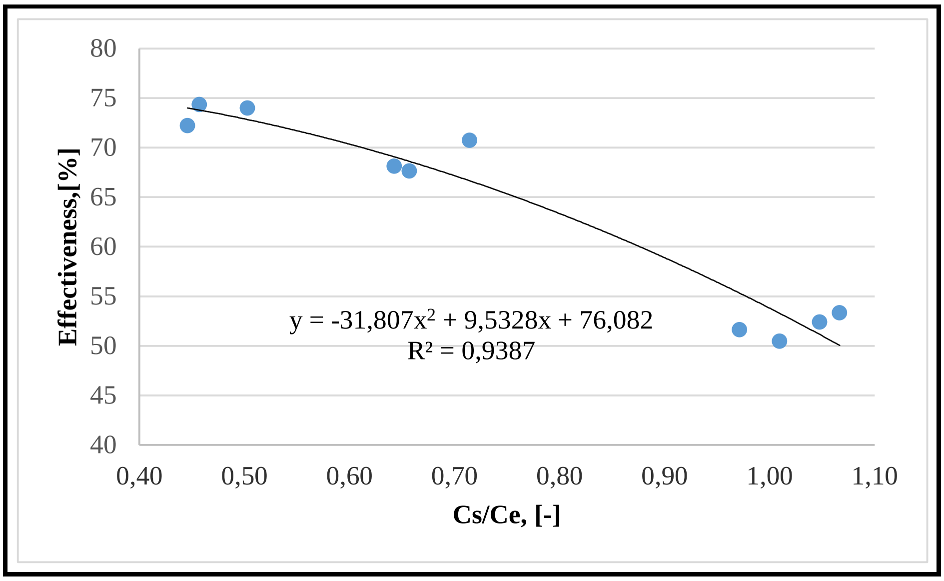

Figure 3. Correlation between effectiveness of supply side of air to air heat exchanger and ratio of heat capacity rates of supply and exhaust air

Conclusions

A daily performance of air handling unit in cooling mode is conducted. Effectiveness of supply side of air to air heat exchanger in range of 50.5 % to 74.3 % is received. Coefficient of performance in range of 0.88 to 2.99 and specific fan power of air handling unit in range of 1.77 kW/(m^3/s) to 3.06 kW/(m^3/s) are received. It was found experimentally that effectiveness of supply side of air to air heat exchanger depends on values of mass flow of supply and the exhaust air. High values of mass flow of exhaust air responds to high effectiveness of supply side of air to air heat exchanger.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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