EXPERIMENTAL STUDY ON THE INFLUENCE OF COOLING WATER TEMPERATURE AND NIGHT VENTILATION ON ENERGY EFFICIENCY THE HVAC SYSTEMS

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Abstract: *The energy performance standards imposed on nZEB buildings require measures to reduce energy consumption. The article presents an experimental study demonstrating the reduction of energy consumption through the optimal control of the ventilation / air-conditioning systems, made in an experimental room arranged in an office building in Timisoara. To demonstrate the increased energy efficiency of the HVAC systems, while maintaining the comfort conditions in the building, four control scenarios were studied by varying the chilled water temperature at the evaporator outlet and cooling mode of the chiller condenser as well as the ventilation effects on the at night.*

Key words: *energy efficiency, HVAC, cooling water temperature, NZEB, night ventilation.*

1. Introduction

Energy efficiency of buildings is a priority of European energy and climate change policies, as well as those on security of energy supply and the fight against energy poverty. The European framework for the regulation of energy efficiency of buildings is defined mainly by the two major directives: the Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive (EED) [7].

The EPBD, adopted in 2002, introduced energy efficiency requirements in national building codes. Its 2010 review introduced the vision of building sector developments towards buildings close to zero energy (nZEB). It has also established a European framework for a common methodology for calculating the energy performance of buildings and imposing minimum energy performance standards in buildings.

Thus, the requirement has been introduced that, until 31 December. 2020, all new buildings will be of the nZEB type and as of 31 Dec. 2018 all new buildings owned and occupied by public authorities are of the nZEB type [7].

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Current regulations have been the basis for studies that offer energy-efficient solutions for existing buildings like accommodation units, buildings with high energy waste [6].

The objective of this paper is to illustrate the optimal control of the ventilation / air conditioning system, whereby at a given cooling load, the total power consumption of the system is minimized, increasing the energy efficiency of the system while maintaining the comfort conditions in the building.

The measurements, which formed the basis of analysis of electricity consumption, were made in an experimental room that is part of an office building.

The experimental stand designed for this purpose is a flexible one consisting of a chiller, air treatment plant, heat recovery and fan convectors. The flexibility of the experimental stand is that it allows the use of three different ventilation / air conditioning systems (HVAC).

2. Presentation of Initial Data about Experimental Room and HVAC Equipment

The experimental room is located in the office building, which can be divided into several thermal zones (Figure 1), depending on the orientation of the external walls and the vertical location.
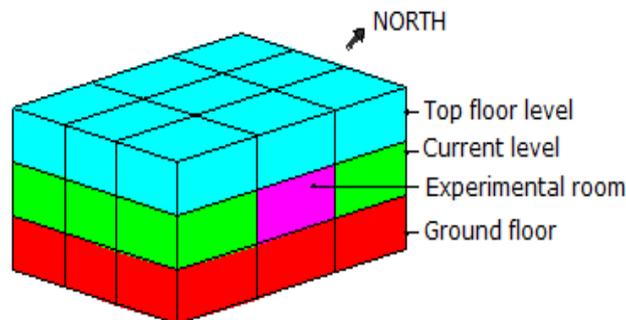
Fig. 1. *Thermal zoning of the office building*

The experimental room located in Timisoara is delimited by an East-facing exterior wall, two interior walls of adjacent offices and an inner wall adjacent to a corridor, a ground floor separating the thermal area studied by a meeting room and a common concrete floor with an office located on the upper level.

The calculations were made for Timişoara, having average daily outdoor air temperature in July, tem = 24.7 °C, absolute air humidity, xe = 10.5 g / kg and the assurance degree of system ventilation / air conditioning of 90%.

The following basic data is also known:
- the height of the room is 3.70 m;
- the total area of the room S = 47m^2;
- the surface of the interior doors Su = 2,10 m^2;
- the glazed surface is 17 m^2 of thermally insulated glass, representing 64% of the exterior wall surface;

- the floor consists of parquet (0.02 m), screed (0.05 m), reinforced concrete slab (0.125 m), lime plaster (0.02 m); the floor is made of sandstone (0.015 m), screed (0.05 m), reinforced concrete slab (0.125 m), lime plaster (0.02 m);
- the outer wall consists of lime plaster (0.02 m), autoclaved cellular concrete (0.25 m), cement mortar plaster (0.03 m) and open brick (0.05 m);
- the inner walls are made of lime plaster (0.004 m), gypsum board (0.02 m) and mineral wool (0.10 m);
- the occupants of the room are 2, each with a computer;
- electric lighting has a thermal break of 5 W / m^2.

Sunset data on a horizontal surface is measured in July at the Solar Radiation Measurement Station (SMRS) at the West University of Timișoara.

The stand used for the researches and measurements carried out is located in the experimental room and consists of the following equipment:
- an air-cooled Daikin chiller with mechanical compression of refrigerant vapor (R410A) with a cooling capacity of 7.1 kW;
- GEA air treatment plant with a maximum air flow rate of 2700 m^3 / h, consisting of a mixing chamber, a fine F5 filter, a hot-dip galvanized heater battery and water-collector-distributor warm, a cooling battery and a centrifugal fan with frequency converter and a maximum pressure loss of 250 Pa;
- a Stiebel Eltron plate heat exchanger with an air flow rate of 520 m^3 / h;
- two wall ventilators, one Climaveneta type and one Rhoss type, with a total cooling power of 3.2 kW.

With the help of the presented equipments can be developed three different ventilation / air conditioning systems (HVAC):
1) Heat Recovery and Fan Coil (RC + VCV).
2) Air Treatment and Ventilation Conduits (CTA + VCV).
3) Air Treatment Center (CTA).

The first system consists of the RC used to provide the minimum fresh airflow required in the room (n = 2 h^{-1}) and the two VCVs for space cooling.

The second system, most commonly used in office buildings, consists of the two VCVs that provide air conditioning for the area and the CTA that blows air at a temperature equal to the temperature set in the interior.

The air flow rate of the boiler is equal to the minimum flow of fresh air required.

The third system consists only of CTA that blows air at 18 °C. Exhaust air flow is variable but does not fall below the minimum required for fresh air.

Regardless of the system used, thermal comfort parameters (24.5 °C ≤ 25.5 °C, ϕi = 40-60%) [3], [4] must be ensured in the room and at the same time to obtain a high energy efficiency of the equipment used.

In order to determine the energy efficiency of the three HVAC systems presented above, four control scenarios were made by modification the chilled water temperature at the outlet from evaporator and the cooling mode of the chiller condenser shown in Table 1.

Scenarios to control system operation   Table 1

Scenarios	Cooling mode of the chiller	Chilled water temperature twr [°C]
1	air	5
2	air-water	5
3	air	8
4	air-water	8

The indoor air temperature was set to the comfort value of 25 °C, and measurements were made within 8 hours for each scenario.

3. The Influence of Chilled Water Temperature on the Energy Efficiency of the HVAC System

To determine the influence of chilled water temperature on electricity consumption, scenarios 1 with 3 and 2 with 4 were compared for each ventilation / air conditioning system.

Table 2 shows the electricity consumption (E_{el}) for two scenarios of the three ventilation / air conditioning systems, resulting in the corresponding ΔE_{el} energy savings.

Influence of chilled water temperature on electricity consumption   Table 2

System		Scenario			
		1	3	2	4
CTA+VCV	E_{el} [kWh]	17.40	17.20	15.27	14.97
	ΔE_{el} [%]	1.15		1.96	
CTA	E_{el} [kWh]	29.54	27.24	20.98	18.94
	ΔE_{el} [%]	7.78		9.72	
RC+VCV	E_{el} [kWh]	8.23	7.84	5.28	4.72
	ΔE_{el} [%]	4.73		10.60	

It is noted that in the case of CTA + VCV and RC + VCV ventilation/climatization systems, a ΔE_{el} electricity saving is recorded when the temperature of the chilled water rises from 5 °C (scenario 1 and 2) to 8 °C (Scenario 3 and 4).

For the CTA system where the share of CTA electricity consumption in the total electricity consumption is high, the increase in chilled water temperature does not lead to energy savings, but on the contrary, the decrease of this temperature from 8 °C to 5 °C leads to economies of energy [1].

In both CTA + VCV and RC + VCV system, the highest energy savings of 1.96% and 10.60%, respectively, is obtained when the chiller is cooled with a air-water mix. In the CTA system, the highest energy saving of 36.43% is obtained when the chiller is air cooled.

It is also noted that the maximum energy saving between the three systems of 36.43% is obtained in the CTA system when the chiller is air cooled.

If an analysis of the electricity consumption in the RC + VCV system is performed only on ventiloconvector representing the air conditioning part, it is found that when the chiller is cooled with spray water and the chilled water temperature is 5 °C (scenario 2), the minimum electricity consumption of 0.46 kWh is recorded on the terminal devices (Figure 2).
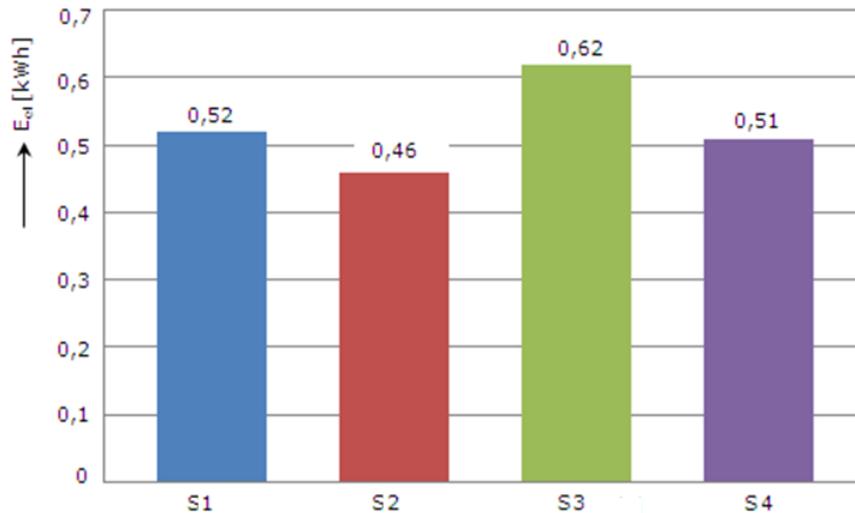
Fig. 2. *The electricity consumption of VCV from the RC + VCV system*
S1, S2, S3, S4 - Scenario 1, 2, 3 and 4

Table 2 shows that of all the solutions analyzed, the minimum electricity consumption of 4.72 kWh is RC + VCV with the chilled air-water chiller and the cooled water temperature of 8 °C (scenario 4).

4. Influence of Night Ventilation on Electricity Consumption

Cooling using night ventilation can be done either by opening the windows or by turning on the ventilation system. For security reasons, the option of opening the windows was not considered, but the night ventilation system with a running time of 8 hours / night was used.

Table 3 shows the values for hourly indoor temperature, outdoor temperature, average radiation temperature and operating air temperature, in case of night ventilation or not.

From the measured value of the air temperature with the help of the black globe, the average radiant temperature value t_{mr} of the room air tmr was determined and the value of the confort operative temperature (t_c) was calculated by means of the relation (1).

If the indoor air velocity $v < 0.4$ m/s and the average radiation temperature $t_{mr} < 50$ °C, then according to [2] the operative temperature can be approximated by:

$$t_c = \frac{t_{mr} + t_i}{2} \tag{1}$$

The difference between *c* and the maximum admissible indoor temperature of 25.5 °C for the summer season in office buildings, according to EN 15251, was determined, recording the surplus of hourly and total degrees.

Values of hourly temperatures with and without night ventilation   Table 3

Night ventilation	Temperature [°C]	Hour						Surplus of grads [°C]
		11	**12**	**13**	**14**	**15**	**16**	
non-existence	t_e	23.7	24.4	25.5	26.3	26.8	27.2	–
	t_i	27.6	27.8	28.0	28.1	28.1	28.2	–
	t_{mr}	28.0	28.2	28.4	28.4	28.3	28.3	–
	t_c	27.8	28.0	28.2	28.2	28.2	28.2	–
	t_c-25.5	2.3	2.5	2.7	2.7	2.7	2.7	15.6
existence	t_i	24.5	25.0	25.4	25.8	26.2	26.2	–
	t_{mr}	24.1	24.4	24.8	25.0	25.2	25.4	–
	t_c	24.3	24.7	25.1	25.4	25.7	25.8	–
	t_c- 25.5	–	–	–	–	0.2	0.3	0.5

In the Table 4 was calculated the Q_{rac} cooling load and the Erac thermal energy for the office considered, corresponding to the indoor air temperature of 24 °C and 25 °C, respectively, in the time interval 11: 00-16: 00.

Cooling load and thermal energy between 11: 00-16: 00   Table 4

Hour	t_e [°C]	t_i = 25 °C		t_i = 24 °C	
		Q_{rac} [kW]	E_{rac} [kWh]	Q_{rac} [kW]	E_{rac} [kWh]
11	23.7	1.54		1.57	
12	24.4	1.36		1.39	
13	25.5	1.36	8.49	1.40	8.71
14	26.3	1.39		1.43	
15	26.8	1.41		1.45	
16	27.2	1.43		1.47	

From the data obtained in Table 4 it results that the thermal energy required for cooling the space with a degree Celsius is equal to 0.22 kWh.

If night ventilation is not used, the thermal energy required to cooling the surplus of 15.6 °C will be 3.43 kWh. Knowing that the chiller has COP = 2,4, it results that the electricity consumed by the chiller is 1.43 kWh.

In case of night ventilation, the thermal energy required to cooling the surplus of only 0.5 °C is 0.11 kWh. For the same of the value COP chiller, the electricity consumed by the chiller is 0.04 kWh, plus the electricity consumed by the night supply air fan motor (at a flow rate of 712 m^3 / h) of 1.12 kWh, resulting in a total electricity consumption of 1.16 kWh. In this case there is a decrease of the electric consumption by 18%, from 1.43 kWh to 1.16 kWh [2].

5. Conclusions

For air-cooled chillers, the performance coefficient increases as the from the outside aspirated air temperature (t_e) decreases and with the temperature of the cooled water (t_{wr}) increases at the outlet from evaporator.

All heat recovery systems can achieve significant energy savings, but require investment and maintenance costs, so an optimization calculation must be performed prior to adopting one system or another.

For ventilation / air conditioning systems CTA + VCV and RC + VCV, a saving of ΔE_{el} energy is recorded when the chilled water temperature increase from 5 °C (scenario 1 and 2) to 8 °C (Scenario 3 and 4), while the CTA system where the share for CTA electricity consumption is high, the increase in chilled water temperature does not save energy.

Although the results show that the RC + VCV system has the highest energy efficiency it is not indicated in office buildings because the architecture of the building is affected by the application of numerous ventilation grills on the facades, and therefore it is recommended to use the CTA + VCV system with chiller cooled with air-water and chilled water temperature of 8 °C.

In the case of night ventilation, there is a decrease in electricity consumption by 18%, from 1.43 kWh to 1.16 kWh.

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