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Effect of the variable air volume on energy consumption - case study

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Abstract. At present, administrative buildings consume more energy than in the past, and they also contribute to environmental pollution. It is an effort to build buildings with minimal energy consumption. The energy consumed to operate the ventilation air is not insignificant. Techniques and control systems allow different ways of saving energy. However, all the savings measures should also take into account the quality of the internal environment for the health of people. This article compares a ventilation system with a constant flow of ventilating air with an air-conditioning system with varying air flow rates ensuring the required air quality.

1. Introduction

At present, administrative buildings are large energy consumers. From the study [1], about 12% of the world carbon dioxide (CO_2) releases in 2010 are generated, directly or indirectly, by producing the needed energy for buildings in order to ensure their adequate operation. Energy use in buildings and the desire to reduce the undesirable CO_2 production from polluting atmospheres is also a motive for making energy use more efficient and reducing overall energy consumption. When reducing the energy intensity of a building, it is also necessary to take into account the quality of the indoor environment, the reduction of which can cause various health problems as well as reduce the performance of employees [2].

One of the options for reducing energy consumption is the use of a variable air volume (VAV) system. A similar issue was dealt with by Eskin and Turkmen [3], who analyzed the annual energy requirements needed to heat and cool the office building in the Turkish climate. Their analysis shows that 48% of the energy was used for heating and 52% for cooling the building. Different studies can see similar proportions in Central Europe as well - depending on the building envelope and climatic conditions that are different.

Despite the fact that the natural advantages of the VAV system in terms of its energy efficiency are well understood, the designer is often subjected to complications due to different building characteristics, different climatic conditions and several zones. In the hot and humid environment, it is often found that the benefits of VAV systems are not fully realized [4]. Therefore, Sekhar [4] examined five different buildings in an environment whose internal load remained constant, but the thermal load caused by the envelope of the building and the orientation differs between the five buildings. This examines the presence of a variety of cooling loads, which then leads to the study of potential energy savings by the VAV system.

In the area of reducing energy consumption, Aunur et al. [5] compared VAV with Variable Refrigerant Flow (VRF) system. In their work they found that a large amount of energy is consumed by the VAV itself. They found that the VRF system is more economical than the VAV system. Huang et al. [6] examined the simulation of the air conditioning control system, where they presented energy savings of 17%. According to Liang et al. [7] it is possible to monitor the ventilation air and optimize the VAV system to achieve energy savings about 28%.

In our article, we compare ventilation system with constant flow of ventilation air with ventilation system with varying ventilation air flow, which is controlled on the basis of the CO_2 concentration at the locations of the persons in the building.

2. Description of the building and ventilation system

2.1 Description of the building

The administrative building is rectangular, without protruding and receding parts. The building has a total of six above-ground floors. On the first floor there is a porter, a room for visits, a sanitary facility, a dining room and a food dispenser. From the second up to the fifth floor there are 44 offices. On the last above-ground floor there is a boiler room and an air-conditioning machine room.


Figure 1. Southeast (left) and northeast (right) view of the building [Source: Jankura D.]

The building should be located in Poprad city, where the external calculation temperature is -16°C and the outside summer calculation temperature is +32°C. The heat transfer coefficient for the peripheral wall U = 0.11 W/(m^2·K), roof U = 0.09 W/(m^2·K), window U = 1.1 W/(m^2·K), door U = 1.9 W/(m^2·K) and thermal resistance for the floor on the ground R = 6.64 (m^2·K)/W. The total design heat capacity is 192 kW. The total amount of heat is 131 kW. Heat gains were calculated separately for months for each building's hours of operation from 7:00 am to 5:00 pm and are listed in Table 1.

Table 1. Heat gains after months

Time	March Q (kW)	April Q (kW)	May Q (kW)	June Q (kW)	July Q (kW)	August Q (kW)	September Q (kW)	October Q (kW)
07:00	67	79	89	86	84	82	60	34
08:00	85	89	95	92	91	93	79	63
09:00	86	89	93	90	91	93	84	75
10:00	77	80	83	82	83	84	78	71
11:00	63	66	70	71	71	71	66	60
12:00	53	58	61	63	64	62	58	52
13:00	59	63	68	68	69	67	63	57
14:00	68	71	75	75	76	75	70	64
15:00	73	76	80	80	80	80	73	66
16:00	71	75	81	80	79	79	70	57
17:00	59	68	76	76	74	72	56	38

2.2 Description of ventilation system

Equipment for air conditioning in the building is divided into five independent air-conditioning systems from an operational and hygienic point of view:

- ventilation and cooling of office space,
- ventilation and cooling of the dining room,
- ventilation of food dispensers,
- ventilation of sanitary facilities.

For the entire building, the heat produced in the boiler room is located on the 6th floor. Cooling is ensured by using chillers placed on the roof.

In the building there is dominant office ventilation, for which a separate air-conditioning unit is used, located in the technical room on the top floor of the building. In all offices, are used comfortable slot connections for the air supply, which are located in the overhead construction. The hoses have a long range of jets and the possibility of changing the flow (horizontal, vertical). To remove dirty air, shock absorbers are built into the roof structure.

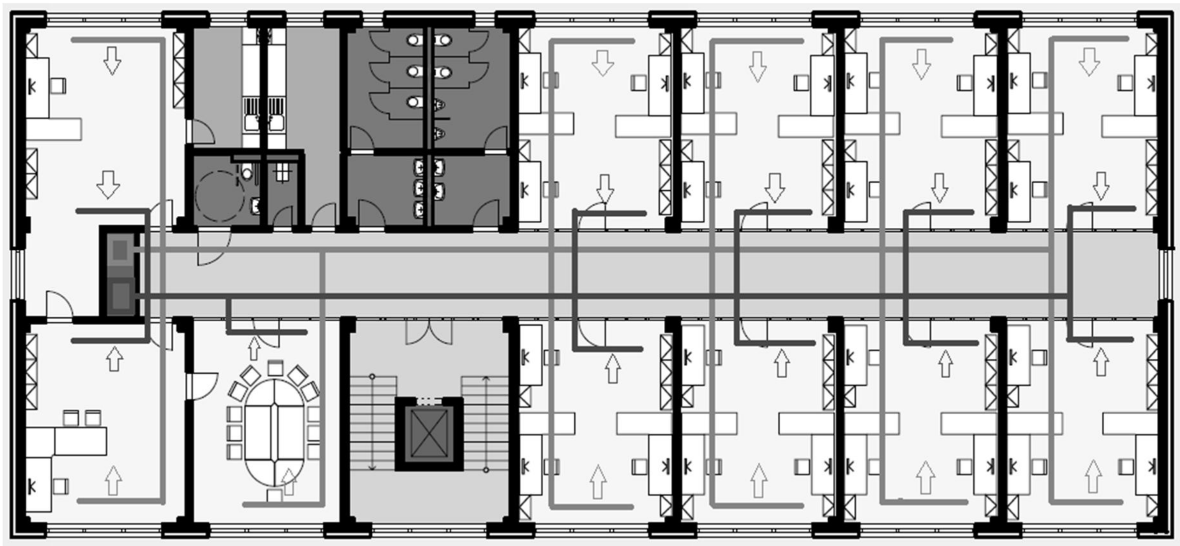

Figure 2. Typical floor plan of the administrative part of the building

3. Calculation of the need heat and cold for ventilation air

The need for heating and cooling for the heat treatment of ventilation air is designed for two versions of the air conditioning system.

3.1 First version of ventilation systems

The first air-conditioning system has a given constant flow of ventilating air during working hours (7:00 - 17:00), which is installed on the total projected number of people in the building. The total projected number of people is 105 people. Calculations are based on the volume flow of air V = 1.31 m^3/s, air density ρ = 1.27 kg/m^3 in winter and air density ρ = 1.18 kg/m^3 in summer, with a thermal capacity c_{pv} = 1.005 kJ/(kg·K) in winter and c_{pv} = 1.01 kJ/(kg·K) in summer. Number of hours of daily operation $n_{h,\,o}$ = 10 h/d. Air temperature control is carried out in the engine room of the air conditioner in accordance with the temperature of the outside air.

3.2 Second version of ventilation systems

The second air-conditioning system has a variable air flow rate during the working hours (7:00 - 17:00), which is controlled by a CO_2 sensor located in each room. The Variable Air Flow (VAV) regulator is installed in front of each room at the inlet and outlet air ducts. If the CO_2 concentration increases in the room, the VAV valve will open to the necessary position. If the CO_2 concentration decreases, the VAV valves will close. The central air handling unit senses the air in the air duct and adjusts the airflow as required. Thus, the reduction of heat consumption for air heating (cooling), as well as the reduction of electricity consumption for fans and pumps is achieved. For the second variant, the calculations take into account the air parameters, as in the first variant.

The maximum estimated number of people is 105 people. Figure 3 shows the occupancy diagram of the building by persons.

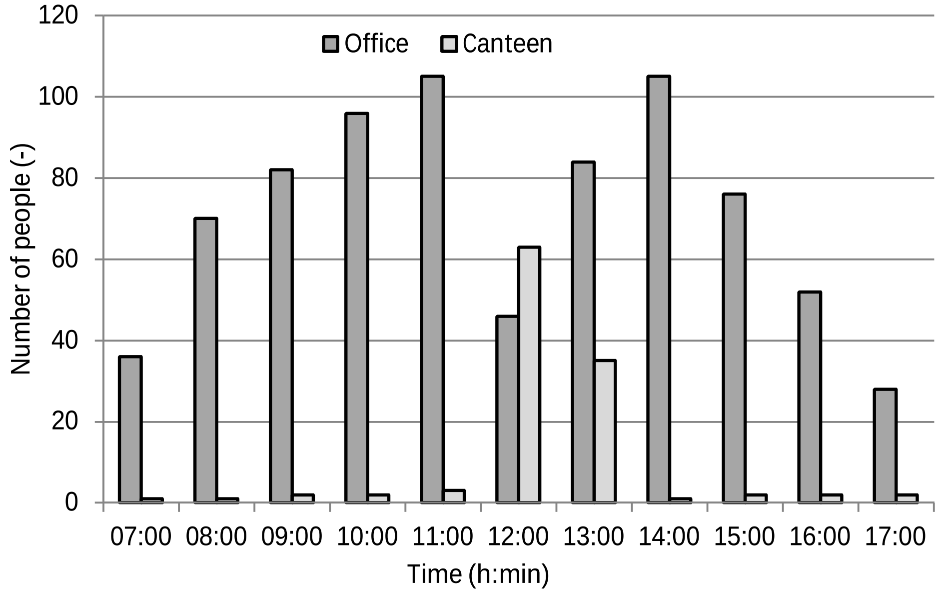

Figure 3. Building occupancy diagram

Due to the varying number of people in the building, it is necessary to consider varying air flow rates. Dosage of fresh air is set at 45 $m^3/(h.pers)$. Predicted air flow rates are shown in Table 2. Average volume air flow rate is 0.89 m^3/s.

Table 2. Ventilation air flow rates

Hour (h:min)	Number of people (-)	Volume air flow V (m^3/h)	Volume air flow V (m^3/s)
07:00	36	1,620	0.45
08:00	70	3,150	0.88
09:00	82	3,690	1.03
10:00	96	4,320	1.20
11:00	105	4,725	1.31
12:00	46	2,070	0.58
13:00	84	3,780	1.05
14:00	105	4,725	1.31
15:00	76	3,420	0.95
16:00	52	2,340	0.65
17:00	28	1,260	0.35

3.3 The heat demand for heating the ventilation air

The heat demand for air heating $Q_{t,\,vent}$ (kWh/year) is calculated according to the following formula:

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$$Q_{t,\,vent} = V_e \cdot \rho_e \cdot c_{pv} \cdot n_h \cdot D_{vent} \tag{1}$$

where: V_e - volume of outside air flow (m^3/s); ρ_e - outdoor air density in winter months (kg/m^3); c_{pv} - specific heat capacity of the ventilation air at constant winter pressure (kJ/(kg·K)); $n_{h,h}$ - hours of operation of the air conditioner (h); D_{vet} - the number of degree days in the period required to heat (K·d) [8].
The received heat demand for air heating for the first and second variants is given in the table. 3

Table 3. The heat demand for heating the ventilation air

Month	First version Without VAV valve D_{vent} (K·d)	$Q_{t,vent}$ (kWh)	Second version With VAV valve D_{vent} (K·d)	$Q_{t,vent}$ (kWh)
January	725	12.410	725	8.438
February	607	10.390	607	7.064
March	517	8.849	517	6.017
April	336	5.751	336	3.910
May	177	3.030	177	2.060
June	84	1.438	84	978
July	28	479	28	326
August	56	959	56	652
September	174	2.978	174	2.025
October	350	5.991	350	4.073
November	498	8.524	498	5.796
December	648	11.092	648	7.541
Total (kWh/year)	∑	71.891	∑	48.879

3.4 The cool demand for cooling the ventilation air
The heat demand for air heating $Q_{c,\,vent}$ (kWh/year) is calculated according to the following formula:

$$Q_{c,\,vent} = V_e \cdot \rho_e \cdot c_{pv} \cdot H_c \tag{2}$$

where: V_e - volume flow of outdoor air in the summer months (m^3/s); ρ_e - density of outdoor air in the summer months (kg/m^3); c_{pv} - specific heat capacity of the ventilation air at constant summer pressure (kJ/(kg·K)); H_c - number of cooling stages (K·h) [8].
The resulting cooling air requirements for the first and second versions are in Table 4.

Table 4. The cool demand for cooling the ventilation air

Month	First version Without VAV valve H_c (K·d)	$Q_{c,vent}$ (kWh)	Second version With VAV valve H_c (K·d)	$Q_{c,vent}$ (kWh)
March	17.5	25	17.5	18
April	34.6	50	34.6	35
May	315.2	456	315.2	317
June	574.2	832	574.2	577
July	768.4	1.113	768.4	772
August	554.8	803	554.8	557
September	241.4	350	241.4	242
October	11.0	16	11.0	11
Total (kWh/year)	∑	3.645	∑	2.528

4. Results and discussion

In order to evaluate the systems, it is also necessary to know the cool demand to remove heat flows from internal heat sources (people, computers, lighting, food etc.), from external heat sources (from radiation, heat transfer through building structures) and the need for electric power to drive fans and pumps. The individual partial calculations are not processed in this article but the results are shown in Table 5.

Table 5. Comparison of energy consumption

	First variant Without VAV valve (kWh/year)	Second variant With VAV valve (kWh/year)
The heat demand for heating the ventilation air	71.891	48.879
The cool demand for cooling the ventilation air	3.645	2.528
The cool demand in the allocation of warm streams from internal heat sources	8.496	5.735
The cool demand in the allocation of warm streams from external heat sources	116.851	116.851
Electricity required for fans and pumps	11.412	5.005

From Table 5, we can see that the heat demand for air heating lower by 32%. Also, the cool demand for air cooling is lower by 31%. The heat demand from internal heat sources is 33% lower. The power requirement for fan and pump drive is 56% lower. The need for cooling to reduce the heat load from outdoor heat generators, which, in the first variant, is 55% remains unchanged and strongly influences the need for energy.

Despite the fact that the second variant has much less energy needs, the total can be calculated after counting the losses for individual energies with a total reduction of only about 4%.

In the second variant, it is necessary to purchase and install a CO_2 sensor in each ventilated room, VAV valve and control valve pair. After a full review of investment and operating costs (investment costs is approximately € 25,230 and operating costs for system with VAV valves is 17,108 Eur/year, systems without VAV valves is 19,533 Eur/year), it can be assumed that after 11 years, CO_2 sensors will be paid, VAV valves and control valves, and after 11 years the VAV valve system will be profitable.

5. Conclusion

Based on the analysis of the ventilation system it can be stated that it is appropriate to install a system with VAV valves for all buildings. Although this system is beneficial for the first period, it is not always beneficial for economic reasons.

However, it is also necessary to look at the environment. By regulating the airflow of the VAV valves, we save about 18% of the energy that needs to be produced and often air pollution. Since, due to 4% annual financial savings, it is not beneficial for an investor to increase both investment and operational costs, so it's beneficial to save the environment. Therefore, it would be necessary for the state to contribute to subsidies to environment-friendly systems.

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References

[1] Pachauri R K, Meyer L A et al. 2014 Climate Change 2014 *Synthesis Report Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC Geneva Switzerland) p 151
[2] Wargocki P 2017 Improving indoor air quality improves the performance of office work and school work and provides economic benefits *Healthy and Sustainable Buildings Conference* (IAQ 2007 Baltimore)
[3] Eskin N and Türkmen H 2008 Analysis of annual heating and cooling energy requirements for office buildings in different climates in Turkey *Energy and Buildings* **40(5)** 763-773
[4] Sekhar S C 1997 A critical evaluation of variable air volume system in hot and humid climates *Energy and Buildings* **26(2)** 223-232
[5] Aunur T N, Hwang Y and Rademarch R 2008 Simulation comparison of VAV and VRF air conditioning systems in an existing building for the cooling season *Energy and Buildings* **41(11)** 1143-50
[6] Huang W Z, Zaheeruddin M and Cho S H 2006 Dynamic simulation of energy management control functions for HVAC systems in buildings *Energy Conversion and Management* **47(7)** 926-943
[7] Liang W, Quinte R, Jia X and Sun J-Q 2015 MPC control for improving energy efficiency of a building air handler for multi-zone VAVs. *Building and Environment (Elsevier)* **92** 256-268
[8] Dahlsveen T, Petras D et al. 2008 *Energy auditing and building certification* (JAGA GROUP Bratislava, Slovak) p 166