Journal of Energy Technology

JET Volume 8 (2015) p.p. 57-68
Issue 4, December 2015
Typology of article 1.04
www.fe.um.si/en/jet.html

DESIGN OF THE VENTILATION AND AIR-CONDITIONING SYSTEM IN AN OFFICE BUILDING

NAČRTOVANJE SISTEMA PREZRAČEVANJA IN KLIMATIZACIJE V POSLOVNI STAVBI

Franc Rihl[R]

Keywords: ventilation and air-conditioning, cooling, heating, ventilation ducts, Brestanica Thermal Power Plant (TEB).

Abstract

This article presents an office building within the Brestanica Thermal Power Plant for which a design of the ventilation and air-conditioning system has been made. First, a brief description of the existing heating and cooling system from the aspect of the operation and the investment contribution is made. Then a ventilation and air-conditioning system is designed based on the geometric characteristics and thermal needs of the building. Calculation of heat losses, selection of an appropriate ventilation and air-conditioning unit, and design of a ventilation duct system are included in the design. The entire system is evaluated from the aspect of investment value.

Povzetek

V članku je predstavljena poslovna stavba v Termoelektrarni Brestanica, za katero se je naredila študija prezračevanja in klimatizacije. Najprej je na kratko opisan obstoječi sistem ogrevanja in hlajenja iz vidika samega delovanja in investicijskega vložka. V nadaljevanju je načrtovan sistem prezračevanja in klimatizacije glede na geometrijske karakteristike in toplotne potrebe.

[R] Corresponding author: Franc Rihl, Faculty of Energy Technology, Tel.: +386 40 792 479, Mailing address: Hočevarjev trg 1, 8270 Krško, E-mail address: franc.rihl1@um.si

V načrtovanje je vključen preračun toplotnih potreb stavbe, izbira ustrezne prezračevalne in klimatske naprave in načrtovanje sistema prezračevalnih kanalov za transport klimatiziranega zraka. Celotni sistem je ovrednoten tudi iz vidika investicijske vrednosti.

1 INTRODUCTION

The aim of this article is to examine the system for heating, cooling, and ventilation in an office building within TEB. The entire study is based on data obtained from TEB; the current embedded system for heating, cooling and ventilation is described based on this data. Furthermore, the total investment costs of both embedded systems are researched and presented.

Based on the size of the business buildings and the calculation of the heat demand, the selection of an appropriate ventilation and air-conditioning unit and the design of the ventilation duct system is presented. This article concludes with an assessment of the investment costs of installing such a system.

2 DESCRIPTION OF THE OFFICE BUILDING

The office building comprises two separate buildings connected by a corridor on the first floor. Therefore, the smaller part of the office building is named ‘Part A’, where the reception and offices are, and the bigger one ‘Part B’, where workshops and a warehouse are. The office building is shown in Figure 1.

Figure 1: *The office building*

The office building is physically separated from the production part of TEB. All relevant information about the office building for further calculation were provided by the head of the TEB, and they are shown in Table 1.

Table 1: *The geometrical characteristics of an office building*

	PART A	PART B
Area of the thermal envelope [m²]	2234.22	3980.50
Conditioned volume [m³]	1741.38	6449.47
Net heated volume [m³]	1286.02	5281.44
Usable area [m²]	494.35	1578.40
Length of the zone [m]	28.42	64.90
Width of the zone [m]	11.50	26.05
Height of the floor [m]	2.40	3.16
Number of floors	2	2
Number of rooms	28	60

Climate characteristics depending on the location of the office building are a temperature deficit of 3100 Kday, a projected temperature of -13 °C and an average humidity of 78%. Depending on the projected temperature, this is the 3rd climate area in Slovenia, [1]. These data are used in the calculation of the transmission heat losses.

3 THE EXISTING SYSTEM FOR HEATING, COOLING AND VENTILATION

The office building does not have a common system for heating and cooling, but it has two entirely separate systems that are independently operating. The old system for heating was upgraded before the heating season in 2006. The old oil boiler system was replaced with a gas-condensing boiler system, with a total heat capacity of 400 kW. The system consists of four Buderus Logamax Plus GB162 boilers connected into a cascade and regulated with two Buderus Logamatic 4000 controllers.

Consumption of natural gas is recorded by a remote system, which is directly connected to the connected gas pipeline. Monthly natural gas consumption between 2011 and 2013 is shown in Figure 1. Annual average natural gas consumption for heating of the office building is 25,732.5 Sm³.

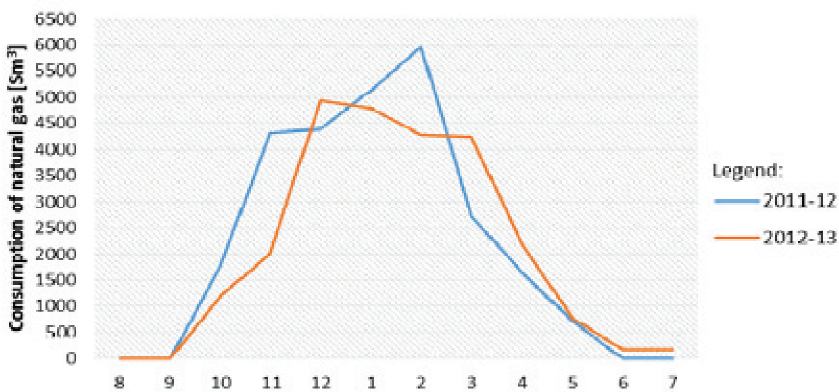

Figure 2: *Consumption of natural gas between 2011 and 2013*

In addition to gas boilers for DHW heating, an air-water heat pump is used. The maximum heat capacity of the heat pump is 5 kW and COP around 2.8. In the event of failure, the old oil boiler system takes over heating, which is connected through a parallel connection and heat exchanger. The total value of the investment in the gas-condensing boiler system was €121,014.86.

The cooling system was mounted in summer 2004. Based on the number of required rooms and necessary cooling capacity, a multi-split unit system was selected. This system consists of 25 units and it is vacuumised and filled with ecologically acceptable R407C liquid. In the entire system is approximately 43 kilos of this cooling fluid. The total value of the investment in the cooling system was €8,863.26.

The office building does not have its own system for ventilation; thus, employees have to provide sufficient air exchange by opening windows and doors. Consequently, this leads to uncontrolled ventilation and heat losses.

4 VENTILATION AND AIR-CONDITIONING SYSTEM

The ventilation and air-conditioning system is concerned with achieving and maintaining thermal comfort parameters in confined areas, [2].

It is a complete process, which includes the production, transport and the injection of the transmission medium into the air-conditioned area. Constant thermal comfort is maintained by regulating the temperature, relative humidity, air velocity, air quality, volume level and differential pressure in the area, [2].

Depending on the scope of operation, two main types of ventilation and air-conditioning system are knowns:

– Comfort, and
– industrial systems, [2].

4.1 Central system for ventilation and air-conditioning

This is the most basic type of a ventilation and air conditioning system from the technical point of view. The transmission medium in this type of system is air. It is accordingly prepared in the central unit; then it is supplied through ventilation ducts in all air-conditioned areas. At the same time, the exhaust air is transported out of the area through the return line of ventilation ducts. Fresh air can be mixed with exhaust air in the mixing chamber in order to reduce energy consumption. However, this mixing process should not significantly affect the thermal comfort in the air-conditioned areas, [2]. An example of the central system for ventilation and the air-conditioning structure is shown in Figure 2.

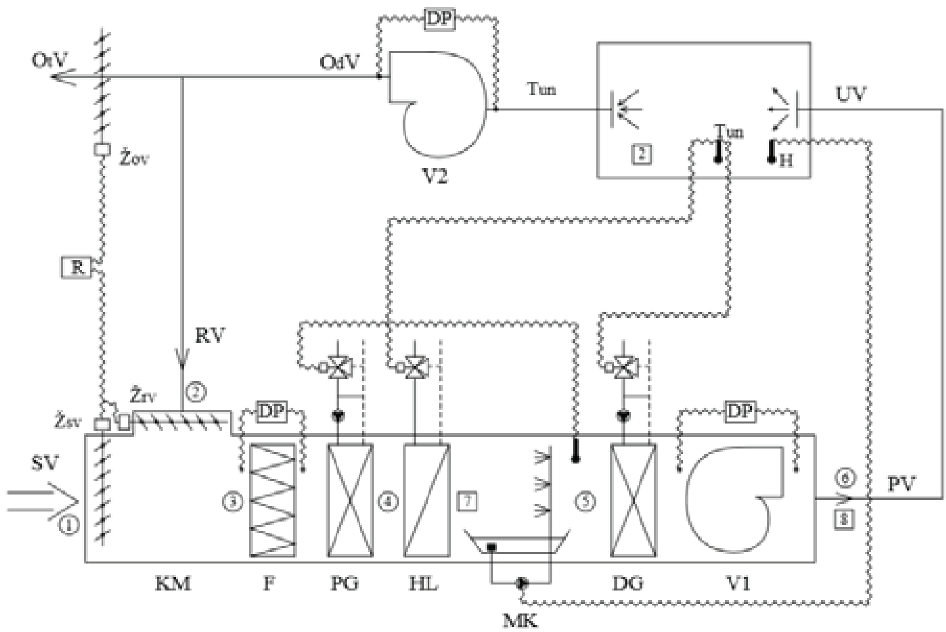

Figure 3: *Structure of the central system for ventilation and air-conditioning*, [2]

5 DESIGN OF VENTILATION AND AIR-CONDITIONING SYSTEM

The design of a ventilation and air-conditioning system includes a calculation of the heating and cooling load of the building according to the information in Table 1. Then, based on the calculated loads and climate data, the size of the central ventilation and air-conditioning unit is chosen. This is done with a numeric program that determines the size of the heater, cooler, heat recovery system and other parts of the system.

After the central ventilation and air-conditioning unit is chosen, a ventilation duct system for transporting air into air-conditioned areas must be designed. This is made by a calculation of ducts dimensions on the basis of the arrangement of the rooms and required air exchange rate. In ventilation ducts, pressure drops occur. Ducts must be designed in such a manner that the fan in the central ventilation and the air-conditioning unit can cover the maximum calculated pressure drop in the system.

5.1 Thermal and cooling load

The thermal load is calculated on the basis of the transmission heat losses of the building and data on the climate in which the building is placed. Cooling load is calculated as the sum of the transmission heat losses and heat gains specified in the German standard VDI 2076. The heat gains described in VDI 2076 are those due to the presence of people, solar radiation gains, the heat of equipment and lighting. Transmission heat losses were calculated in the program URSA GF 4.0, which is made for calculating the thermal protection of buildings and energy use in buildings in accordance with the regulation on energy efficiency PURES 2010. The data in Table 2 are calculated using Equations 5.1 to 5.4 and the program URSA GF 4.0.

$$\dot{Q}_{HL} = \dot{Q}_{T} \cdot \Delta T \tag{5.1}$$

$$\dot{Q}_{p} = \left(\dot{Q}_{p_{tr}} + \dot{Q}_{p_{f}}\right) \cdot N \tag{5.2}$$

$$\dot{Q}_{M} = 4 \cdot A_{u} \tag{5.3}$$

$$\dot{Q}_{S} = \left[A_{i} \cdot I_{max} + \left(A - A_{i}\right) \cdot I_{difmax}\right] \cdot b \cdot s_{a} \tag{5.4}$$

Table 2: *Calculated data for thermal and cooling load*

	PART A	PART B
Thermal load		
Transmission heat losses [W]	36,145.23	63,931.23
Cooling load		
Transmission heat losses [W]	6,571.86	11,624.46
Heat gains due to people presence [W]	4,945.00	9,890.00
Heat of the devices and lighting [W]	1,977.40	6,313.60
Solar radiation gains [W]	26,800.66	26,907.45
Total cooling load [W]	40,294.92	54,735.51

5.2 Selection of the ventilation and air-conditioning unit

The company Menerga Ltd. has helped with the selection of a ventilation and air-conditioning unit. This company is primarily engaged in ventilation and air-conditioning systems. According to the data calculated in Table 2, they have selected an Adconair 76 ventilation and air-conditioning unit with the counterflow plate heat exchanger and an air compressor cooling system. For Part A, an Adconair Ad 761601 IMH unit was selected with a heat capacity of 55.99 kW, a cooling capacity of 41.87 kW and a 92% heat recovery rate. For Part B, an Adconair Ad 761501 IMH unit was selected with a heat capacity of 87.53 kW, a cooling capacity of 55.45 kW and a 93% heat recovery rate.

Despite all the characteristics, units do not have an integrated system for heating the water heaters. A solution to this manner had to be found, which was the design of the pipeline from the gas condensing boilers to both units.

5.2.1 Design of the pipeline

The pipeline has to connect gas condensing boilers and both units and provide the required heat capacity. The transmission medium in the pipeline is water, and the operating temperature is 70/50 °C. The pipeline consists of several main elements:

- pipes,
- heat exchanger,
- expansion vessel, and
- water pump.

Due to the required heat capacity of the water heaters, the pressure drop in the pipeline, and the velocity of medium and thermal insulation of pipes, a Danfoss XB 59M-1 70 heat exchanger, an OPTIMA 200 expansion vessel, Uponor Ecoflex Thermo Twin 2×63×5.8/200 DN50 pipes and a Grundfos Magna3 50-40 water pump have been selected.

5.3 The dimensions of ventilation ducts

In the office building, a dual ventilation duct system was designed for each part of the building. This was done on the basis of the technical characteristics of the ventilation and air-conditioning units.

The first step was the selection of air velocity through different elements of the ventilation duct system. Recommended values of air velocity are shown in Table 3.

Table 3: *Recommended values of air velocity through different elements of the ventilation duct system*, [3]

Element	The approximate values of the air speed [m/s]	
	Comfort system	Industrial system
Protective gratings	2–4	4–6
Main ducts	4–8	8–12
Side ducts	3–5	5–8
Air diffusers	1,5–2,0	3–4

The second step is the calculation of the cross-section of the ventilation duct according to Equation 5.5 [3].

$$A_{PK} = \frac{\dot{V}}{3600 \cdot w} \tag{5.5}$$

When the calculation of cross-sections of all ducts is done, it is necessary to select a sufficiently large ventilation duct. Recommended sizes of the rectangular ventilation ducts are shown in Table 4.

Table 4: *Recommended sizes of the ventilation ducts,* [3]

Designation	b	h	Surface [m²]
300/150	300	150	0.0450
400/200	400	200	0.0800
500/250	500	250	0.1250
600/300	600	300	0.1800
600/350	600	350	0.2100
700/400	700	400	0.2800
800/500	800	500	0.4000
1000/500	1000	500	0.5000

Protective gratings are selected using Equation 5.6, for which the required effective surface must be larger than the calculated [4].

$$A_{ef2} = B1 \cdot \left(H1 - 21 - \left(7 \cdot n\right)\right) \tag{5.6}$$

The air diffusers are selected according to the required effective surface and injecting speed of air via diagrams, which can be found for special types of diffuser, [4].

5.4 The calculation of the pressure drop in the ventilation ducts

For the ventilation duct system, it is necessary to calculate the maximum possible pressure drop and verify whether it can be covered with the air fans built in the ventilation and air-conditioning units. The maximum possible pressure drop typically occurs in the longest duct. The pressure drop is caused by two types of pressure drops:

- linear, and
- local.

Typically, these pressure drops are calculated using Equations 5.7 to 5.10.

$$\Delta p = \sum \Delta p_{lin} + \sum \Delta p_{lok} \tag{5.7}$$

$$\Delta p_{lin} = \frac{\varepsilon \cdot \rho \cdot w^2}{d_H \cdot 2} \cdot L \tag{5.8}$$

$$d_H = \frac{2 \cdot a \cdot b}{a + b} \tag{5.9}$$

$$\Delta p_{lok} = \zeta \cdot \frac{\rho \cdot w^2}{2} \tag{5.10}$$

The rooms in which the maximum pressure drops in the system were calculated are shown in Table 5.

Table 5: *Calculated pressure drops in the ventilation ducts*

Place	Pressure drop	
	Supply [Pa]	Outlet [Pa]
Part A		
Office 1.1	477.78	400.90
Reception	398.64	307.90
Part B		
Office 1325	661.13	583.24
Warehouse	633.54	567.78

All calculated pressure drops are smaller than the maximum allowed pressure drops of the air fans inside the ventilation and air-conditioning units, which means that the system of ventilation ducts is appropriately designed.

6 FINAL VALUE OF THE INVESTMENT

The investment in the ventilation and air-conditioning system consists of several sets. The main sets are the ventilation and air-conditioning units and elements related to their operation, followed by the ventilation duct system, protective gratings, diffusers and works related to the installation of equipment.

The values shown in Table 6 are based on data obtained from different manufacturers, such as Menerga Ltd., NKM Ltd., Hidria Ltd., Danfoss Ltd., Uponor Corporation, Štern Ltd. and Grundfos Ltd.

Table 6: *Total value of the investment*

Type of costs	Total value without VAT [€]
Equipment – ventilation and air-conditioning units	186,147.00
Equipment – pipeline	7,223.39
Installation and mounting costs, additional work	19,500.00
Total value without VAT [€]	212,870.39
VAT 22 % [€]	46,831.49
The final value of the investment [€]	259,701.88

Certain values are assumed, since it is difficult to estimate the exact value of the services. In that manner, the final value of an investment may be different than it would have been if the project is actually performed.

7 CONCLUSION

This paper describes the current situation in terms of thermal comfort in an office building. A major shortcoming is uncontrolled ventilation, an oversized gas condensing system, and insufficient cooling of the entire building. The consequences of such situation are higher maintenance costs, and deficits or surpluses of fresh air, which leads to uncontrolled heat losses and higher operating costs. In the ventilation and air-conditioning system, such problems do not occur, because the automation maintains optimal thermal comfort.

From the aspect of investment, it can easily be seen that the investment in the designed system is almost twice as high as in the old one. Another disadvantage is the usage of the gas condensing system for heating the water heaters of the designed system. This application has reduced the investment costs. It can be concluded that the designed system would not be worth the investment, because such systems are typically installed in new buildings.

References

[1] *Podatki za pravilnik o učinkoviti rabi energije*, Državna meteorološka služba – METEO [world wide web], available at: http://meteo.arso.gov.si/met/sl/climate/tables/pravilnik-ucinkoviti-rabi-energije/(3. 9. 2015)

[2] **B. Todorović,** *Klimatizacija*, Savez mašinskih i elektrotehničkih inženjera i tehničara Srbije (SMEITS), Beograd, 2005

[3] **Recknagl, Šprenger, Šramek, Češerković,** *Grejanje i klimatizacija*, sedmo, izmenjeno i dopunjeno izdanje, Interklima, Vrnjačka Nanja, 2011

[4] *Distribution and control air,* brochure, Hidria Ltd. [world wide web], available at:
http://si.hidria.com/si/klima/programi/distribucija-regulacija-zraka/ (25. 10. 2014)

[5] **F. Rihl,** *Načrtovanje sistema prezračevanja in klimatizacije v poslovni stavbi*, master's thesis, 2015

Nomenclature

(Symbols)	(Symbol meaning)
TEB	Thermoelectric power plant Brestanica
DHW	domestic hot water
SV	fresh air
T	thermometer
KM	mixing chamber
H	hydrostat
F	filter
V2	fan for air extraction
PG	preheater
OdV	used air
HL	cooler
OtV	exhaust air
MK	chamber for air humidification

Žrv	grate of the recycled air
DG	heater
Žsv	grate of the fresh air
V1	fan for air supply
Žov	grate of the used air
PV	conditioned air
DP	differential pressure switch
UV	supply air in the area
RV	recycled air
$\dot{Q}_{HL}$	transmission heat losses [W]
$\dot{Q}_{T}$	heat flux [W]
ΔT	temperature difference [K]
$\dot{Q}_{p}$	heat gains due to people presence [W]
$\dot{Q}_{p_{tr}}$	sensitive heat [W]
$\dot{Q}_{p_{f}}$	latent heat [W]
N	number of people
$\dot{Q}_{M}$	heat of the devices and lighting [W]
A_{u}	usable area [m²]
$\dot{Q}_{S}$	solar radiation gains [W]
A_{i}	glass surface of the window [m²]
I_{max}	global solar radiation [W/m²]
A	total surface of the window [m²]
I_{difmax}	diffuse solar radiation [W/m²]
b	transmittance
s_{a}	the coefficient of accumulation
A_{PK}	cross-section of the duct [m²]
$\dot{V}$	volume air flow [m²/h]
w	air velocity [m/s]
A_{ef2}	effective surfice of protective grating [m²]

$B1$	width of protective grating [m]
$H1$	height of protective grating [m]
n	number of lamells
Δp	total pressure drop [Pa]
Δp_{lin}	linear pressure drop [Pa]
ε	the coefficient of the material roughness
ρ	density of the medium [kg/m^3]
d_H	hydraulic diameter [m]
L	length of the duct [m]
a, b	dimensions of the duct[m]
Δp_{lok}	local pressure drop [Pa]
ζ	the coefficient of the local resistance