DEVELOPMENT OF AIR HANDLING UNITS ENERGY CONSUMPTION CALCULATION PROGRAM

GAISA APSTRĀDES IEKĀRTAS ENERĢIJAS PATĒRIŅA APRĒĶINA PROGRAMMAS IZVEIDE

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Summary

Energy consumption of HVAC systems in modern buildings is increasing very significantly. Ventilation and cooling system consumes 1/3 of total building's energy consumption [1]. Combination of air handling units' optimal technical characteristics with good control system can minimize costs and energy demand. Research of the air handling units' optimal technical characteristics requires understanding of indoor climate energy and moisture gains, quantity of moist air to be supplied considering a fast changing of outside air parameters.

Introduction

This paper reports on energy calculation program development for the air handling units. The air handling units' energy consumption depends on thermodynamic properties of moist air. The program is developed for the energy consumption calculation of air handling units with heat recovery sections (both temperature and humidity recovery), recirculation section (adiabatic mixing of two most air streams), heating section, cooling /dehumidification section, humidification section, supply and exhaust fans. The program calculates heat and electrical energy consumption of an air handling unit per year according to known (or measured) exhaust air temperature and humidity and variable outside air temperature and humidity.

Methods

The program is written in Matlab programming language with graphical user interface and plotting functions of results. Every hour from 8760 h per year the program calculates the necessary heating / cooling dehumidification / humidification power according to the air mass, exhaust, supply, the outside air parameters and air handling units' configuration. Electrical power of fans for the air distribution is calculated according to the air mass, fans efficiency, air ducts resistance. The energy consumption is calculated as a sum of heating, cooling and electrical energy demand per hour.

Climate inLatvia

Latvia is located in the moderate climatic zone. Its temperature, moist climate is created by the Atlantic air masses and influenced by the Baltic sea and the gulf of Riga. The outside air very rarely corresponds to the necessary supply air parameters (see Figure 1). The rest of the time the air should be heated, cooled, humidified or dehumidified to achieve the necessary air temperature and humidity in premises.

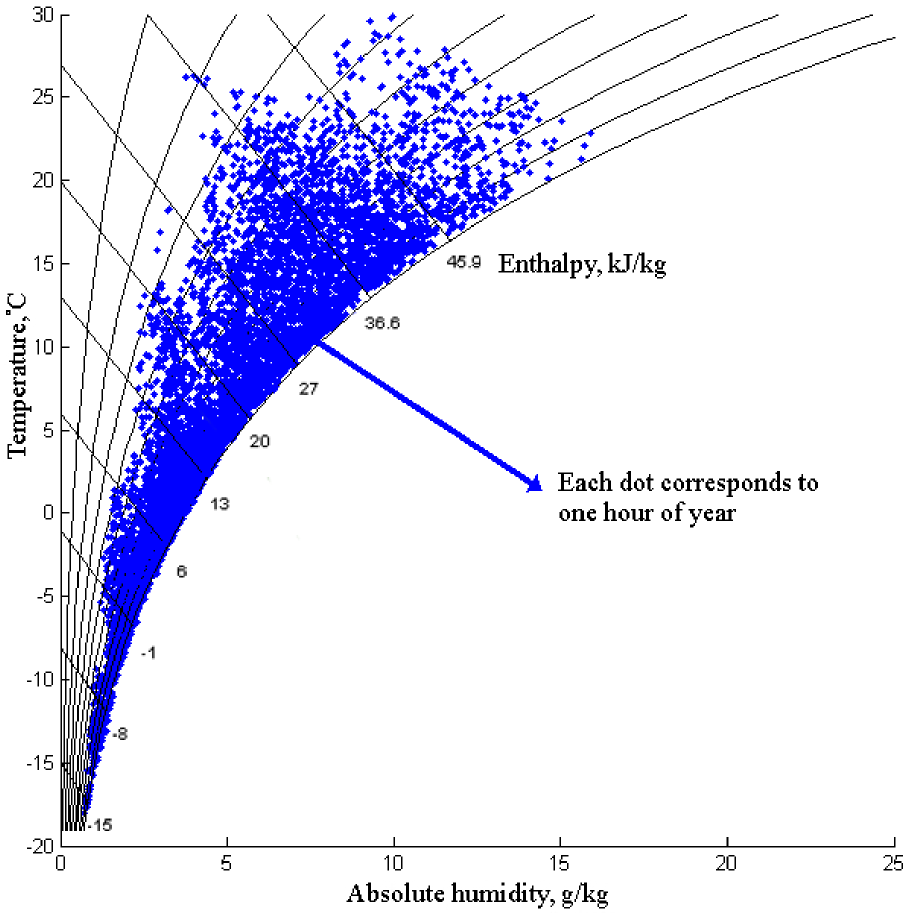

Figure 1. Average meterological year of Latvia

The energy calculations of the air handling units is based on Latvia's average meteorogical year, which was developed [12] according to "National renewable energy Labaratory's" [8] principles. Each dot in Figure 1 (temperature, absolute, relative air humidity) corresponds to one hour of the average year.

POWER CALCULATIONS OF AIR HANDLING UNIT

Known parameters of the outside and exhaust air are: air volume m^3/h; barometric pressure (101,325 kPa), temperature C^0, relative humidity $\%$. Before calculations of power it is necessary to calculate the air parameters according to [3]: water vapor saturation pressure kPa; water vapor pressure kPa, absolute humidity kg/kg, the specific volume of air m^3/kg, mass of air kg/s, enthalpy kJ/kg, dew point temperature C^0, wet bulb temperature C^0. All these parameters are necessary for calculation of energy consumption.

Power calculation of air heating:

$$Q = m_{da}(h_2 - h_1)\text{, } kW \tag{1}$$

where Q – necessary heating power, kW; m_{da} - mass of air, kg/s; h_2 - enthalpy of air after heating kJ/kg; h_1 - enthalpy of air before heating kJ/kg.

Power calculation of air cooling:

$$Q = m_{da}(h_1 - h_2)\text{, kW} \tag{2}$$

where Q – the necessary cooling power, kW; m_{da} - the mass of air, kg/s; h_2 - the enthalpy of air after cooling kJ/kg; h_1 - the enthalpy of air before cooling kJ/kg.

Air parameters calculation of two air streams adiabatic mixing:

$$m_{da1}h_1 + m_{da2}h_2 = m_{da3}h_3, \tag{3}$$

$$m_{da1} + m_{da2} = m_{da3}, \tag{4}$$

$$m_{da1}W_1 + m_{da2}W_2 = m_{da3}W_3, \tag{5}$$

where masses of air m_{da1} and m_{da2} are mixed together, W absolute humidity of air *g/kg*.

Heat recovery:

Heat recovery depends on the heat recovery efficiency (temperature and humidity) and mass flow differences [illegible] Time, h [illegible] uming equal mass flows, temperature and hu[illegible]ulated:

$$t_3 = \eta_{temp} \cdot (t_2 - t_1) + t_1,\ C^0 \tag{6}$$

where t_3 - the supply air temperature C^0; t_2 - the exhaust air temperature C^0; t_1 - the outside air temperature C^0, η_{temp} - the temperature efficiency of heat recovery equipment.

$$W_3 = \eta_{hum} \cdot (W_2 - W_1) + W_1\text{, } kg/kg \tag{7}$$

where W_3 - the supply air absolute humidity kg/kg; W_2- the exhaust air absolute humidity kg/kg; W_1- the outside air absolute humidity kg/kg, η_{hum} - the humidity efficiency of heat recovery equipment.

Humidification section:

The energy calculations program calculates steam humidifier section (temperature is constant). The necessary humidification can be calculated as:

$$WP_3 = m_{da}(W_3 - W_1)\,,\ kg/kg \tag{8}$$

where WP_3 - the necessary supply air absolute humidity kg/kg; W_3 - the supply air absolute humidity kg/kg; W_1- the outside air absolute humidity kg/kg. Steam humidifiers consumes electrical energy, usually according to the steam humidifiers technical data to evaporate 1 kg humidity requires 0.75 kW of electrical power.

Calculation of supply / exhaust fans electrical power:

Fans' electrical energy power depends on air ducts resistance, fans efficiency and air volume. The fans electrical power can be calculated as:

$$P = \frac{\Delta p \cdot q_v}{\eta_v \cdot \eta_m \cdot \eta_t}\,,\ kW \tag{9}$$

where P – the necessary electrical power of fan kW ; Δp - pressure rise in fan Pa , η_v - fan's efficiency coefficient; η_m - motor efficiency coefficient; η_t - transmission efficiency coefficient, q_v - air volume m^3/s .

Supply air volume, temperature and humidity parameters calculation of air handling unit

The quantity of supply air and its parameters are calculated as a necessity to remove given amounts of energy and water from the space to achieve the necessary temperature and relative humidity. The condition line of supply air:

$$\frac{h_2 - h_1}{W_2 - W_1} = \frac{\Delta h}{\Delta W} = \frac{q_s + \Sigma(m_w h_w)}{\Sigma m_w}\ ,\ kJ/kg \tag{10}$$

$$m_{da} = \frac{q_s + \Sigma(m_w h_w)}{h_2 - h_1}\ ,\ kg/s \tag{11}$$

where q_s - the net sum of all sensible heat gain arising from transfer through boundaries and from sources within the space, *kW*; Σ_{mw} - the net sum of all rates of moisture gain arising from the transfer through boundaries and from the sources within the space, kg/s ; h_w - the specific enthalpy of the added water vapor *kJ/kg*.

The minimum quantity of supply air shall correspond to the norms of air exchange per hour.

Practical calculations of air handling unit

The air handling unit with rotary heat exchanger, water heating coil, water cooling coil and the second water heating coil is analyzed as a practical example of energy consumption calculation program.

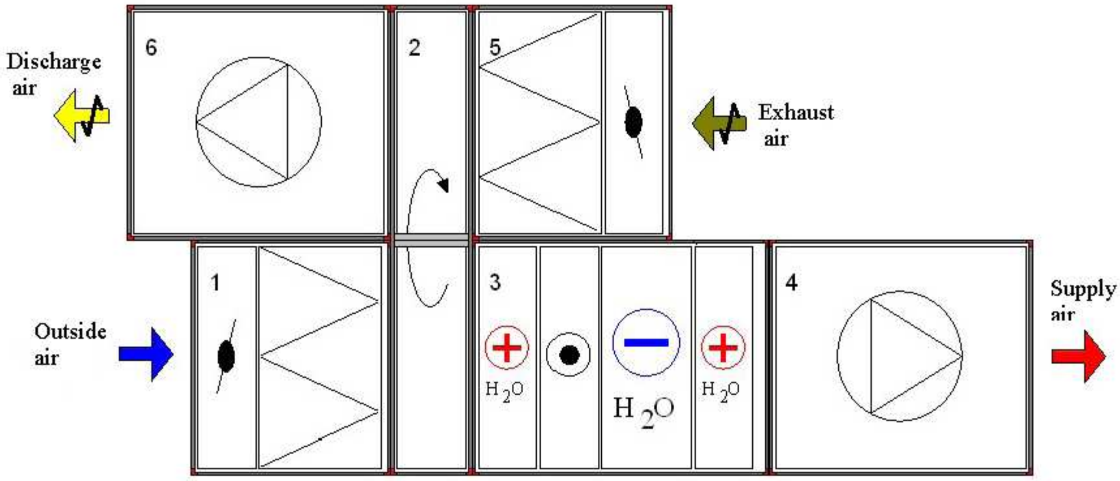

Figure 2. Air handling unit configuration for energy consumption calculation

Air handling unit data are according to Table 1.

Table 1 Air handling unit specification

Electrical power of supply / exhaust fans, kW	9.6 / 7.8
Total pressure supply / exhaust fans, Pa	1225 / 932
Air volume of supply / exhaust fans, m^3/h	18000 / 18000
Temperature / humidity efficiency of rotating heat exchanger	0.74 / 0.64
Nominal heating power of heating coil, kW	50
Nominal cooling power of cooling coil, kW	190
Nominal heating power of second heating coil, kW	75

Several assumptions have been made for calculation and analyze of the air handling unit's energy consumption:

a) the air handling unit is working all year (8760h);
b) fans operates on nominal speed;
c) the condition line $\frac{\Delta h}{\Delta W}$ is 6,2 kJ/g;
d) for achieving room's temperature 23 ^{0}C, 8 g/kg absolute humidity (45% relative humidity) at exhaust air parameters 26.2 ^{0}C and 8.8 g/kg absolute humidity (exhaust air parameters are not changing during a year), supply air parameters should be 20 ^{0}C and 7.1 g/kg absolute humidity according to the air handling unit's air volume, see in Table 1.
e) air distribution effect on room's temperature is not considered;
f) air is dehumidified to cooling coil temperature 9.3 ^{0}C.

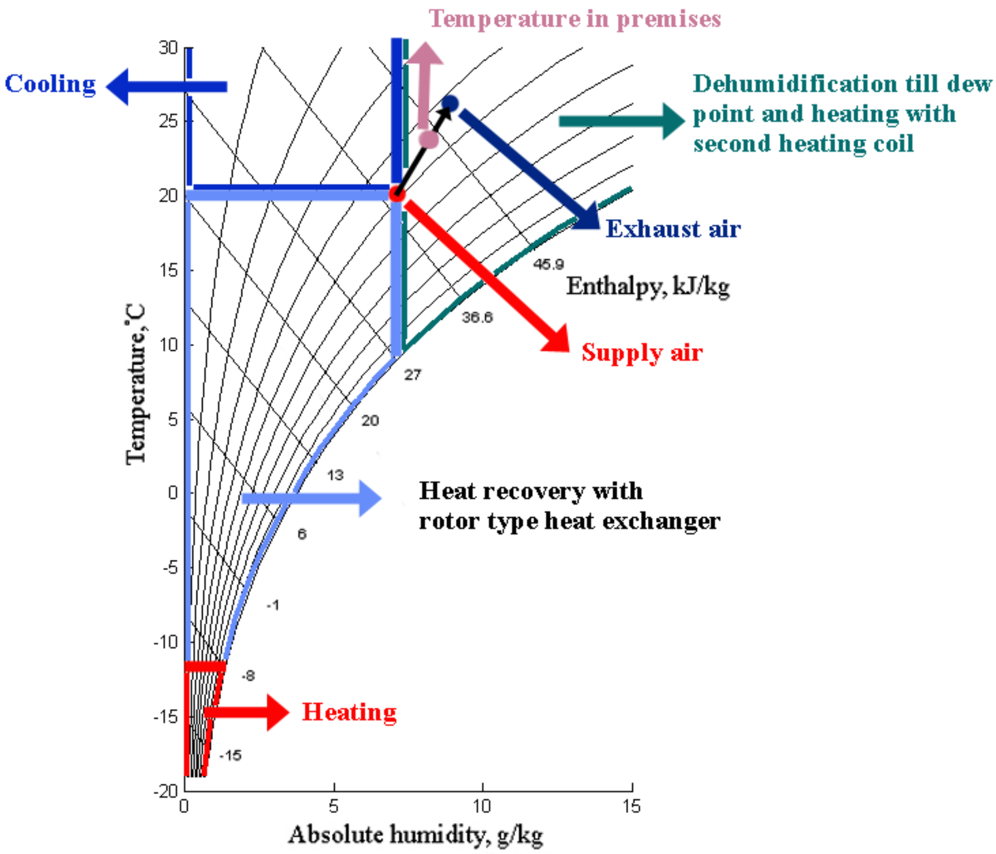

Figure 3. Air handling process analyze to achieve the necessary supply temperature

Practical calculations showed that the air should be heated, if the outside temperature is lower than –12 ^{0}C (Fig. 3).

Supply air temperature after rotating heat exchanger

Rotating heat exchanger is activated, when the outside temperature is lower than 20^{0}C and the absolute humidity is lower than 7.1 g/kg. The air handling unit's rotating heat exchanger is equipped with frequency converter, which allows to limit the supply air temperature and humidity (20^{0}C, 7.1 g/kg). The rotating heat exchanger is operating also in summer, when the outside air temperature is higher than exhaust air temperature and the outside air humidity is higher than exhaust air humidity.

The air handling unit's energy consumption is calculated without the work of rotating heat exchanger in summer and with work of rotating heat exchanger in summer regime. Figure 4 shows supply air parameters after the rotating heat exchanger. Each dot in Figure 4 corresponds to 1 hour.

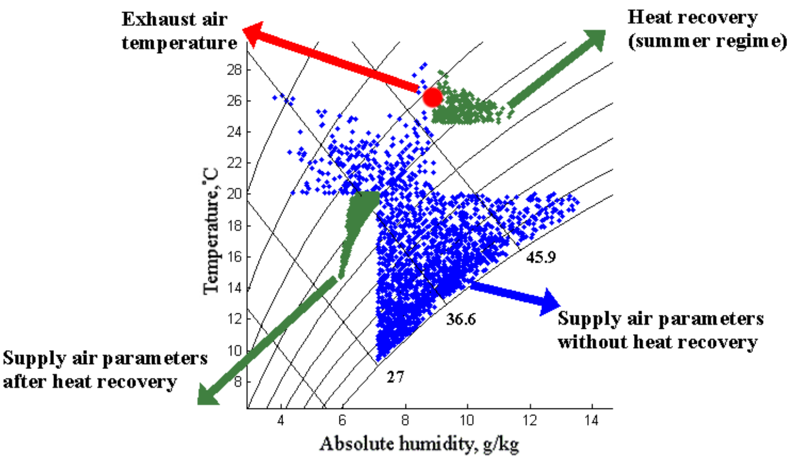

Figure 4. Supply air temperature after heat recovery

RESULTS

According to the supply air temperature and humidity after the heat recovery, the supply air is heated, cooled or dehumidified.

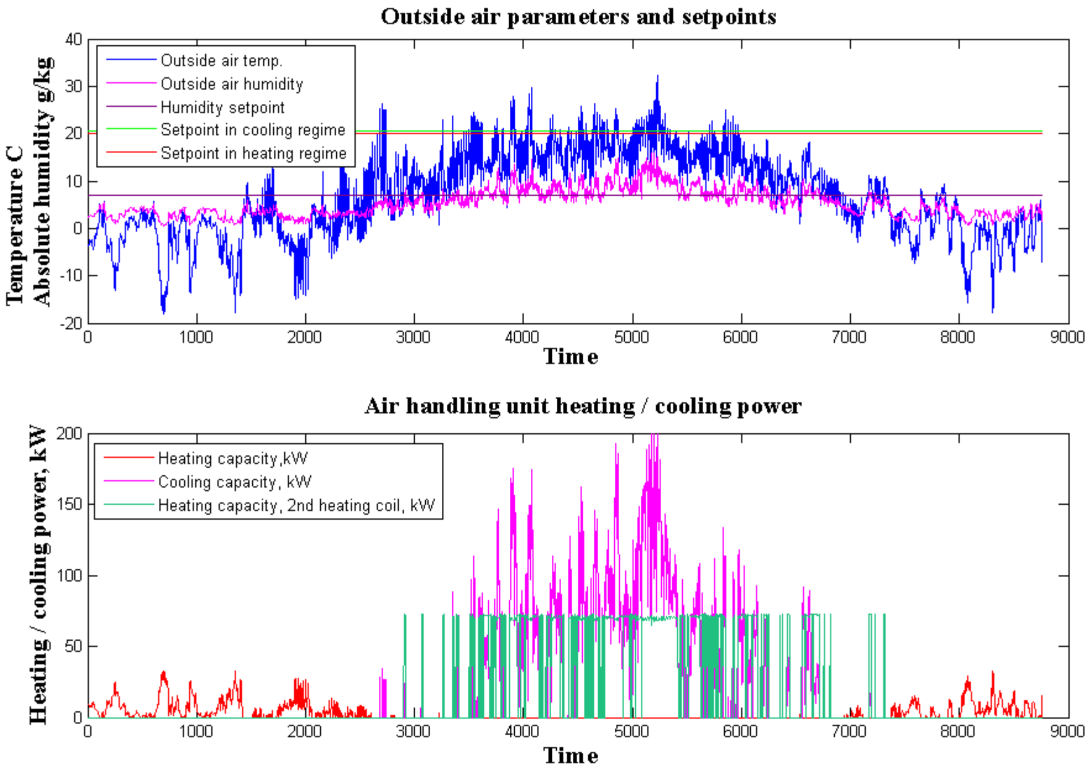

Figure 5. Power calculations for every hour according to necessary supply air parameters. Program calculates total energy consumption of air handling unit per year.

Table 2.Energy consumption of air handling unit

Energy consumption of heating coil, kWh	24 516
Energy consumption of cooling coil, kWh	173 342
Energy consumption of second heating coil, kWh	159 218
Electrical energy consumption of fans, kWh	151 985
Electrical energy consumption of rotating heat exchanger (motor power 100W, operating hours 2720h per year), kWh	272
Electrical consumption of control system (200W), kWh	1750

The rotating heat exchanger in summer regime works just 300h per year. The calculation was done without the work of rotating heat exchanger in summer regime. In this case, cooling power increases for 178kWh (0.1%), heating power with the second heating coil increases for 110kWh (0.07%).

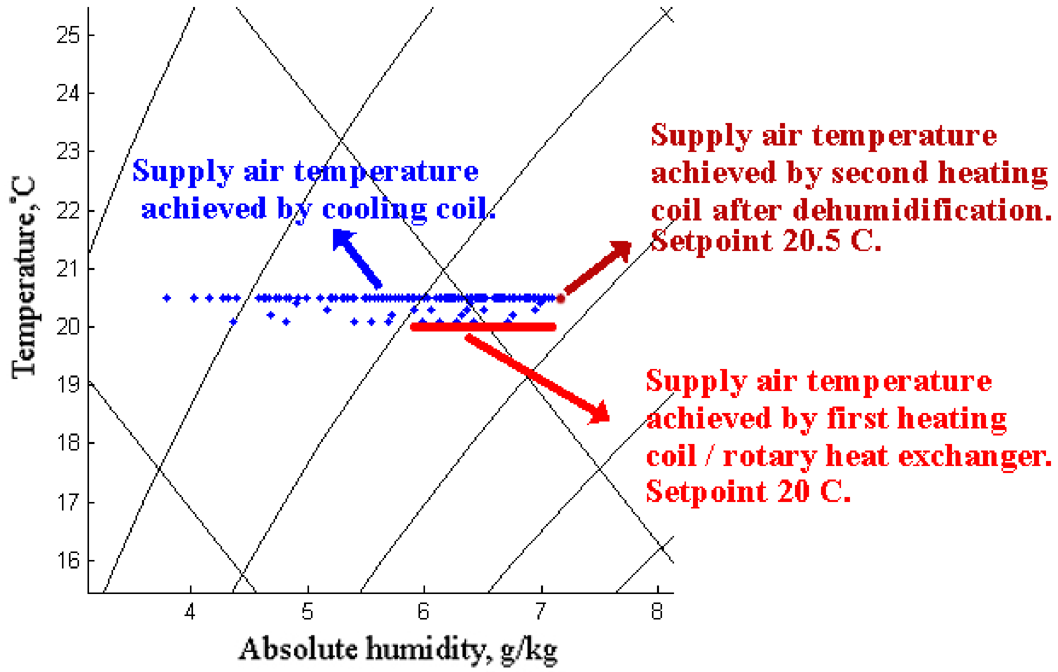

Figure 6.The supply air parameters after air handling

CONCLUSION

The air handling units' power consumption calculation program is a the first step for the development of good control system for the air handling unit. The graphical analyze of the processes gives information about the necessity of temperature, humidity sensors and their location places. The power calculations of the air handling unit's heating and cooling coils show the necessary power requirements for different regimes, and the supply air parameters can be calculated when there is a luck of heating / cooling power.

Known necessary parameters of the supply air and the use of the energy calculation program allow to choose the correct configuration of the air handling unit. The supply air parameters and its effect on the air handling unit's configuration and control system should be investigated more.

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Krūmiņš A., Dzelzitis E., Lešinskis A. Gaisa apstrādes iekārtas enerģijas patēriņa aprēķina programmas izveide.

Darbā ir izklāstīta metodika gaisa apstrādes iekārtas enerģijas patēriņa programmas izveidē. Gaisa apstrādes iekārtas enerģijas patēriņa programma ir izveidota, izmantojot "Matlab" programmēšanas valodu. Programma nodrošina gaisa apstrādes iekārtas jaudu aprēķinu sildīšanas, dzesēšanas, sausināšanas, mitrināšanas un enerģijas atguves režīmiem. Kā izejas dati tiek izmantots Latvijas vidējais metereoloģiskais gads un zināmi nosūces gaisa parametri. Rakstā ir parādīts piemērs enerģijas patēriņa aprēķinam gaisa apstrādes iekārtai ar sildīšanas, siltuma atguves, dzesēšanas un sausināšanas režīmiem. Pieplūdes gaisa parametri tiek aprēkināti pēc siltuma un mitruma *izdalījumiem telpā, zinot vēlamo telpas temperatūru un gaisa daudzumu. Programma aprēķina nepieciešamās jaudas režīmiem (sildīšana kW, dzesēšana un sausināšana kW, ventilatoru jauda kW) ar stundas intervālu. Enerģijas patēriņš gadā (8760h) tiek iegūts, summējot iegūtās jaudas. Ir izanalizēta rotējošā reģeneratora darba lietderība vasarā. Gaisa apstrādes iekārtas jaudu analīze, ņemot vērā procesa virzienu telpā, ļauj efektīvāk izvēlēties gaisa apstrādes iekārtas konfigurāciju, kā arī dod nepieciešamo informāciju gaisa apstrādes iekārtas automatizācijas izveidē.*

Krūmiņš A., Dzelzitis E., Lešinskis A. Development of air handling units energy consumption calculation program.

This paper reports on development of air handling unit's calculation program. Air handling units calculation program is developed, using "Matlab" programming language. Program ensures air handling unit power calculation for heating, cooling, dehumidification, humidification and energy recovery regimes. Average meteorology year of Latvia and known exhaust air parameters are used as input data. Energy calculation of air handling unit with heat recovery, cooling, heating and dehumidification regimes is done as example of program capabilities in this paper. Supply air parameters are calculated according to heat and moisture gains in premises, when there is known necessary room temperature and air volume. Program calculates necessary power for each regime (heating kW, cooling kW, dehumidification kW, fans power kW) with interval 1 hour. Energy consumption is calculated as a sum of all power. Rotating heat exchanger work efficiency in summer is analyzed.

Analyze of power of air handling unit with calculation of supply air condition line, gives benefits in selection of air handling units configuration and gives the necessary information for the development of the air handling unit's control system.

Круминьш А., Дзелзитис Е., Лешинскис А. Создание программы расчета потребления энергии для воздухообработочного агрегата.

В работе изложена методика создания программы по расчету потребления энергии воздухо-обработочным агрегатом. Программа по расчету потребления энергии воздухообработочным агрегатом создана на базе языка программирования "MATLAB". Программа обеспечивает расчет мощностей воздухообработачного агрегата в режиме обогрева, охлаждения, сушки, увлажнения и в режиме возврата. В качестве исходных данных использован средний метереологичиский год Латвии и известные параметры вытяжного воздуха. В статье рассмотрены примеры для расчета потребления энергии для воздухо-обработочого агрегата в режиме обогрева, охлаждения, сушки и в режиме возврата тепла. Параметры притока воздуха рассчитываются, исходя из выделения тепла и влажности в помещении, зная желаемую температуру помещения и объем воздуха. Программа вычисляет необходимую мощность с интервалам в 1 час для режимов (обогрева кW, охлаждение и обсушивание кW, мощность вентиляторов кW). Потребление энергии в год (8760h) рассчитывается, суммируя полученные мощности. Проанализирована целесообразность работы вращающегося регенератора в летний период. Анализ мощностей воздухо-обработочого агрегата, учитывая направления процесса в помещении, позволяет эффективнее выбрать конфигурацию воздухообработочого агрегата, а также предоставляет необходимую информацию для автоматизации воздухообработочого агрегата.