HVAC System Energy Performance Analysis in Office Buildings

(Irodaépületek épületgépészeti rendszerének energiahatékonysági vizsgálata)

Harmati Norbert[1], Dr. Magyar Zoltán[2]

Összefoglalás

A dinamikus szimuláció lehetővé teszi az épületek energiahatékonyságának a vizsgálatát, felmérését és részletes értékelését. A cikk egy irodaház termikus modelljének éves energiaszükségletét vizsgálja dinamikus szimuláció (EnergyPlus® program) alkalmazásával. Az alapmodell az irodák tervezési iránymutatásai alapján készült, majd a tényleges épületburok, az épületgépészeti rendszer, a felhasználó komfortigényét biztosító paraméterek, az üzemeltetési menetrend és kihasználtság alapján készült a dinamikus szimuláció. A vizsgálat során elemeztük és értékeltük az éves energiafogyasztást az idő függvényében. A kutatást dinamikus szimuláció használatával végeztük el, elemeztük és összehasonlítottunk három épületgépészeti rendszer energiaigényét.

A cikk a Magyar Épületgépészek Napja Oktatási nap PhD szekciójában elhangzott előadás alapján készült.

Summary

Simulation-based building performance allows the detailed assessment of energy consumption in buildings. This paper presents a dynamic EnergyPlus simulation of a thermal office building model which evaluates the performance and energy requirement between three HVAC system types. The basic model was developed according to the guidelines of designing office spaces, accessories and communication. The parameters of the building envelope, HVAC, user comfort, schedules and occupancy are defined in the dynamic simulation. The model is constructed as a result of parameterization to analyze and evaluate the influence of the elements on the total energy consumption on an annual basis. The research was conducted through dynamic simulation in order to analyze and compare the energy requirement of three HVAC system types, heating- and cooling loads. Furthermore the efficiency of the heat recovery was also investigated in order to determine its importance of application.

Keywords – Building energy simulation; EnergyPlus® simulation, energy performance

1. Introduction

A great amount of World's energy demand is connected to the built environment. The connection between the increased CO_2 discharge to the atmosphere and the use of energy is also a motive to render a more efficient energy usage, and lowering the total energy demand [1]. Electricity, heating, cooling and ventilation account one third of total energy consumption in office buildings. Therefore, the goal is to find an alternative solution in order to reduce the energy demand and losses. Numerous researches have been devoted in order to investigate the energy performance of buildings in the commercial sector [2], [3].

Building energy efficiency and building performance topics were elaborated via investigations of existing office buildings and computational building models respectively. Simulation-based building performance allows detailed assessment of energy consumption in buildings, to analyze the energy performance. We can examine the influence of each factor extensively and systematically utilizing a dynamic energy simulation tool such as EnergyPlus®, which allows flexibility of the energy model and variability of the construction elements, material properties, lights, three HVAC system types and occupants. The parametric model was developed according to the standards of designing office work spaces, accessories and communication. The parameters of user comfort are implemented from the weather data with the location: Belgrade, Serbia.

The results of the energy simulation outline major criteria for qualitative enhancement. The investigation concerns the following objectives:

a. Modelling a basic medium office building according to the functional disposition of office work spaces;

b. Implementation of weather data, location data, construction sets and materials, schedules for operation of lighting, HVAC, and occupancy;

c. Performing an annual energy simulation, 8760 hours with hourly time step;

d. Evaluation of three HVAC system types influence on the total annual energy consumption and investigating the efficiency of heat recovery.

[1] Department of Civil Engineering, Faculty of Technical Sciences, University of Novi Sad, Serbia
PhD hallgató, tanársegéd, Újvidéki Műszaki Tudomány Egyetem, Építésszervezés és Építéstechnológia Kar, Építészeti Tanszék, e-mail: *harmati@uns.ac.rs*

[2] Department of Building Energetics and Building Service Engineering, Faculty of Architecture, Budapest University of Technology and Economics. Társtémavezető, BME Épületenergetikai és Épületgépészeti Tanszék, e-mail: *magyar@egt.bme.hu*

2. Parametric analysis model

The parametric model is constructed as a medium office building consisting of 8 offices, entrance, hall and WC, shown in **Table 1**. The climate and location data were used from the weather file of the US Department of Energy. [4] The location of the following building model is Belgrade, Serbia.

The setup of the parametric model was performed in **Open Studio1.0.0** and **EnergyPlus® 7.2** program [5],[6]. The building elements, HVAC system, occupants, electric equipment, lighting and schedule sets form the input data for the energy simulation. EnergyPlus® requires spaces to be transformed into thermal zones in order to define the properties necessary for the calculation of the energy loads.

2.1. Schedules and construction

The thermostat schedules were calibrated to the following, **Table 2**.

The schedules for the operation of the building equipment, interior lights and occupants were also set up for the date, time and scale of the function.

For the construction the ASHRAE 189.1 Climate zone 7-8 Construction Set was used. The elements which were modified in the exterior surface construction are the exterior walls, while in the sub-surface construction double layer technical glass was applied for the windows.

The layers for the new construction elements are shown in **Table 3**, and the surface properties are shown in **Table 4**.

The building envelope and window to wall ratio is shown in **Table 5**.

2.2. HVAC system types

Three HVAC systems have been modeled regarding the system type and fuel. The systems consists of supply and demand equipments, which are shown in **Table 6**.

Table 1 Spaces

Space	Area [m^2]	Volume [m^3]	Space	Area [m^2]	Volume [m^3]
Office 1	48.27	168.95	Office 6	16.53	57.85
Office 2	48.27	168.95	Office 7	16.53	57.85
Office 3	48.27	168.95	Office 8	16.53	57.85
Office 4	16.53	57.85	Corridor	60.00	210.0
Office 5	16.53	57.85	WC	12.50	43.75
Area Sum [m^2]		**300.00**	**Volume Sum [m^3]**		**1 050.00**

Table 2 Thermostat schedules

Schedule	Date	Time	Temperature limit
Office Cooling Setup Schedule	01.05 – 30.09	Mo. to Fri. 7 – 18 h	24 °C
Office Heating Setup Schedule	01.10 – 30.04	Mo. to Fri. 7 – 18 h	21 °C

Table 3 Modified construction set properties

Exterior wall	Properties	Windows	Properties
120 mm brick	d = 0.1016 m c = 0.89 W/mK ρ = 1920 kg/m^3 Q = 790 J/kgK	6 mm glass panel	Solar transmittance 0.4296 Solar reflectance 0.5204 Visible transmittance 0.4503 Conductivity 0.0089 W/mK
100 mm insulation	d = 0.1016 m c = 0.03 W/mK ρ = 43 kg/m^3 Q = 1210 J/kgK	13 mm air gap	d = 0,0127 m
200 mm concrete block	d = 0.20 m c = 1.11 W/mK ρ = 800 kg/m^3 Q = 920 J/kgK	Low E-layer	Hard coat insulated glass R= 2.45
19 mm wall air space resistance	D = 0.019 m R = 0.15 m^{2}K/W	6 mm glass panel	Solar transmittance 0.4296 Solar reflectance 0.5204 Visible transmittance 0.4503 Conductivity 0.0089 W/mK
19 mm gypsum board	d = 0.19 m c = 0,16 W/mK ρ = 800 kg/m^3 Q = 1090 J/kgK		

Table 4 Surface properties

	Construction	Reflectance	*U*-Factor with Film [W/m^2-K]	*U*-Factor no Film [W/m^2-K]
SURFACE	Exterior wall	0.30	0.244	0.253
	Ground floor slab	0.30	1.627	2.692
	Roof	0.30	0.156	0.160
	Window (Double-layer)	**Glass *U*-Factor [W/m^2-K]**	**Glass SHGC**	**Glass Visible Transmittance**
		0.988	0.290	0.271

Table 5 Window-, wall-area and window-wall ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m^2]	264.80	84.00	48.40	84.00	48.40
Window Opening Area [m^2]	88.19	25.20	14.52	33.95	14.52
Window – Wall Ratio [%]	33.30	30.00	30.00	40.42	30.00

Table 6 HVAC system equipments

	Heat pump air to air	Natural gas and electricity	Electric system
Supply equipment	1. Coil cooling dx single speed 2. Coil heating dx single speed 3. Coil heating electric 4. Variable speed fan 5. Setpoint manager single zone reheat	1. Coil cooling dx single speed 2. Coil heating gas 3. Variable speed fan 4. Setpoint manager single zone reheat	1. Coil cooling dx single speed 2. Coil heating electric 3. Variable speed fan 4. Setpoint manager single zone reheat
Demand equipment	• **Zone 1** Air terminal single duct VAV with electric reheat • **Zone 2** Air terminal single duct VAV with electric reheat • **Zone 3** Air terminal single duct VAV with electric reheat • **Zone 4** Air terminal single duct VAV with electric reheat	• **Zone 1** Air terminal with gas reheat • **Zone 2** Air terminal with gas reheat • **Zone 3** Air terminal with gas reheat • **Zone 4** Air terminal with gas reheat	• **Zone 1** Air Terminal Single Duct Parallel PIU Reheat • **Zone 2** Air Terminal Single Duct Parallel PIU Reheat • **Zone 3** Air Terminal Single Duct Parallel PIU Reheat • **Zone 4** Air Terminal Single Duct Parallel PIU Reheat

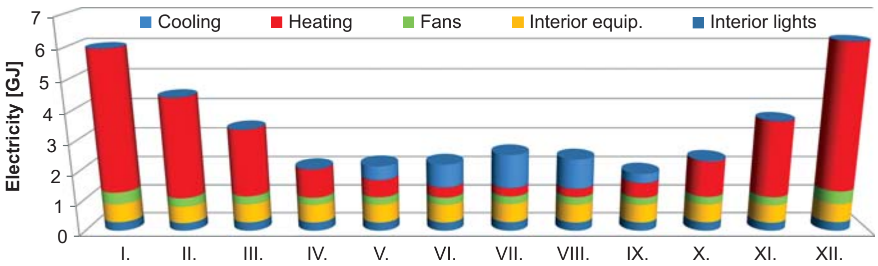

Fig. 1 Building Energy Performance – Electricity – Heat Pump

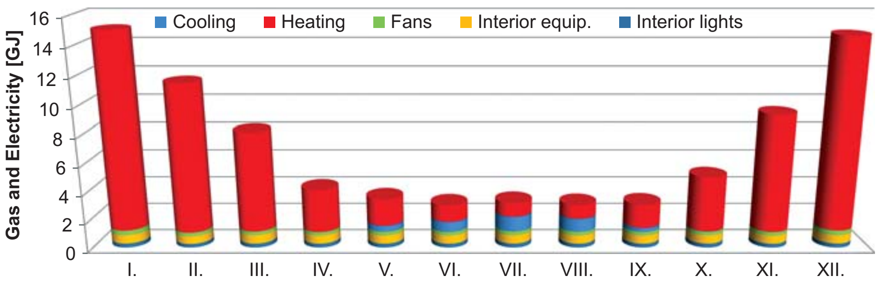

Fig. 2 Building Energy Performance – Electricity, Natural Gas – Gas system

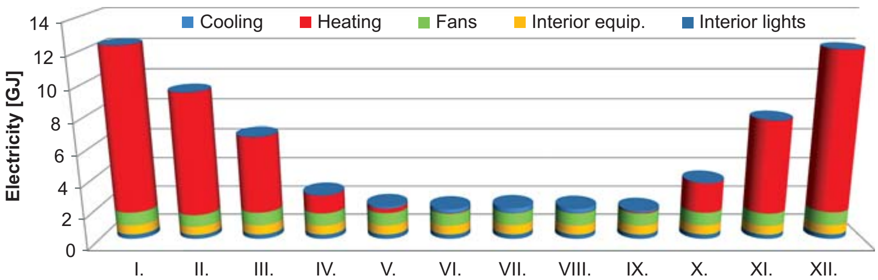

Fig. 3 Building Energy Performance – Electricity – Electric system

3. Simulation and results

The simulation was performed for a period of one year, 8760 hours with one timestep calculation per hour. The obtained results are shown below in **Fig.1, 2, 3** and **Table 7, 8, 9**. The electricity consumption was calculated for heating, cooling, fans, interior lighting and equipment, while the natural gas consumption was calculated for the heating demand.

In order to assess the efficiency of the Heat Recovery (HR) system the primary simulation was ran without the application of the HR.

The HR – Rotary Heat Exchanger unit was connected to the Air Loop Outdoor Air System.

The comparison among the energy demands in these three cases of HVAC systems can be compared in primary energy form, since the supply fuel varies. The conversion factor for electricity for the Serbian Kolubara power plant is $f_{prime} = 3{,}5$ and the conversion factor for gas is $f_{prime} = 1{,}1$. The results in **Table 10** and **Table 11** show the total energy requirement converted into primary energy.

The conclusion of the evaluated systems is that the most preferable system for heating and cooling would be the Heat pump and the Natural gas combined with electricity, since the primary energy need for these systems with the Heat Recovery application is approximately equal. While the electric system requires roughly 36% more primary energy, which results in more carbon emission negative for the environment. Furthermore Table 11 gives an overview of the heating and cooling demand compared to the total energy demand. The results show the importance of the Heat Recovery system, since it lowers the proportion between the heating and cooling loads, and the total energy demand. The applied HR system's sensible and latent effectiveness is 75%.

The comparison among the HVAC system electricity intensity is shown in **Table 12**, without and with the application of the Heat Recovery. This analysis helps us understand that the application of the HR system results in

Table 7 Energy requirement

	Interior Lights: Electricity [kJ]	Interior Equipment: Electricity [kJ]	Fans: Electricity [kJ]	Heating: Electricity [kJ]	Cooling: Electricity [kJ]
Annual Sum	3 385 260	7 276 360	3 454 200	21 597 400	3 639 150
Min. of Months	259 563	558 036	247 351	279 563	–
Max. of Months	292 409	623 717	428 937	4 843 900	1 102 130

Table 8 Energy requirement

	Interior Lights: Electricity [kJ]	Interior Equipment: Electricity [kJ]	Fans: Electricity [kJ]	Heating: Electricity [kJ]	Heating: Gas [kJ]	Cooling: Electricity [kJ]
Annual Sum	3 385 260	7 276 360	3 235 510	280 553	66 264 500	3 515 930
Min. of Months	259 563	558 036	247 351	–	983 390	39
Max. of Months	292 409	623 717	335 115	208 595	13 768 100	1 070 810

Table 9 Energy requirement

	Interior Lights: Electricity [kJ]	Interior Equipment: Electricity [kJ]	Fans: Electricity [kJ]	Heating: Electricity [kJ]	Cooling: Electricity [kJ]
Annual Sum	3 385 260	7 276 360	9 880 920	43 158 800	1 076 290
Min. of Months	259 563	558 036	766 661	11 589	95
Max. of Months	292 409	623 717	859 494	10 572 200	308 811

Table 10 Primary energy demand

Heat pump air to air	Natural gas and electricity	Electric system
	Primary energy	
127 kWh/m^2/yr	124 kWh/m^2/yr	209 kWh/m^2/yr
Σ 38 255 kWh/yr	Σ 37 451 kWh/yr	Σ 62 965 kWh/yr
	Primary energy with Heat Recovery	
87 kWh/m^2/yr	84 kWh/m^2/yr	135 kWh/m^2/yr
Σ 26 351 kWh/yr	Σ 25 332 kWh/yr	Σ 40 670 kWh/yr

Table 11 Heating and cooling loads

Heat pump air to air	Natural gas and electricity	Electric system
	Heating and cooling demand	
Σ 24 566 kWh/yr	Σ 20 248 kWh/yr	Σ 43 006 kWh/yr
64% of the total energy requirement	54% of the total energy requirement	68% of the total energy requirement
	Heating and cooling demand with Heat Recovery	
Σ 12 785 kWh/yr	Σ 8 581 kWh/yr	Σ 20 693 kWh/yr
48% of the total energy requirement	34% of the total energy requirement	51% of the total energy requirement

Table 12 Utility use per total floor area

HVAC System	Without Heat Recovery HVAC Energy Intensity [kWh/m^2]	With Heat Recovery HVAC Energy Intensity [kWh/m^2]
Heat Pump	21.15	15.56
Natural Gas and Electricity	6.65 Electricity 62.72 Gas	6.21 Electricity 26.59 Gas
Electric	51.24	29.50

lower energy requirement for the function of the system itself shown in kWh/m^2 intensity per total floor area of 300 m^2.

From the following analysis and comparison it is clear that the heat pump system and the natural gas system require the least amount of primary energy. The carbon emission with the lower primary energy requirement is also reduced. Since the electric system requires the greatest amount of energy the best solution is to use energy from renewable energy sources with conversion factor close to 1.

Conclusion

Building energy simulation presents a potential overview of the energy performance in buildings and gives a greater understanding of the energy consumption in each sector. This method assists the engineers in decision making with dynamical calculation of the energy consumption. With calibration of the model properties and mechanical systems it is possible with professional intervention to reduce the energy demand or to direct the requirements to an alternative sector where necessary.

References

[1] Nurdil Eskin, Hamdi Türkmen, Analysis of annual heating and cooling energy requirements for office buildings in different climates in Turkey, Energy and Buildings 40 (2008) 763–773, doi:10.1016/j.enbuild.2007.05.008
[2] I. Sartori, A.G. Hestnes, Energy use in the life cycle of conventional and low-energy buildings: A review article, Energy and Buildings 39 (2007) 249–257, doi:10.1016/j.enbuild.2006.07.001
[3] Nelson Fumo, Pedro Mago, Rogelio Luck, Methodology to estimate building energy consumption using EnergyPlus Benchmark Models, Energy and Buildings 42 (2010) 2331–2337, doi:10.1016/j.enbuild.2010.07.027
[4] http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_about.cfm
[5] http://openstudio.nrel.gov/
[6] http://apps1.eere.energy.gov/buildings/energyplus/?utm_source=EnergyPlu&utm_medium=redirect&utm_campaign=EnergyPlus%2BredirecPrimary energy demandt%2B1