ENERGY PERFORMANCE MODELLING AND HEAT RECOVERY UNIT EFFICIENCY ASSESSMENT OF AN OFFICE BUILDING

by

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This paper investigates and analyzes a typical multi-zone office building's annual energy performance for the location and climate data of central Belgrade. The aim is to evaluate the heating, ventilation and air conditioning system's and heat recovery unit's performance in order to conduct the most preferable heating and cooling solution for the typical climate of Belgrade city. The energy performance of four heating, ventilation and air conditioning system types (heat pump – air to air, gas-electricity, electrical and fan coil system) was analyzed, compared and evaluated on a virtual office building model in order to assess the total annual energy performance and to determine the efficiency of the heat recovery unit's application. Further, the parameters of an energy efficient building envelope, heating, ventilation and air conditioning system, internal loads, building operation schedules and occupancy intervals were implemented into the multi-zone analysis model. The investigation was conducted in EnergyPlus simulation engine using system thermodynamic algorithms and surface/air heat balance modules. The comparison and evaluation of the obtained results was achieved through the conversion of the calculated total energy demand into primary energy. The goal is conduct the most preferable heating and cooling solution (best case scenario) for the climate of Belgrade city and outline major criteria in qualitative enhancement.

Key words: *energy performance, EnergyPlus, heating, ventilation and air conditioning, heat recovery, total energy, primary energy*

Introduction

The built environment evidently has the highest energy demand in the world, which is a contemporary problem of consideration. The connection between the energy demand and the increased CO_2 discharge to the atmosphere is a great motive to render a more efficient energy usage [1]. Therefore, the goal is finding 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 [2-4]. Building energy efficiency and building performance topics were elaborated via investigations of existing office buildings and computational building models, respectively [5]. Simulation-based building performance allows de-

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tailed assessment of energy consumption in buildings. Current energy consumption in the building sector is approximated to 40% of the total energy consumption in the world. Therefore, the primary parameters that mostly affect the commercial buildings energy performance are the heating and cooling requirements during the working hours. This paper elaborates the performance of four heating, ventilation, and air conditioning (HVAC) system types and arguments the efficiency and importance of the heat recovery (HR) unit's application.

Studies have been conducted for energy performance assessment in the early design stages since energy simulation was not integrated into the decision-making process [6]. Numerous proposals have been applied in order to reduce the annual heating and cooling energy demand, as for example double skin façades which represent an additional skin on the outside wall of the building [7]. Thermal mass impact on the energy demand has also been analyzed in the function of occupant comfort to investigate the reduction of the energy requirements from the mechanical systems [5].

The motivation of the investigation was to find respectable answers for improvement of the current heating and cooling supply systems of inefficient office buildings in Serbia. Findings could be extended further for different building types and climatic conditions.

The purpose of the investigation is to analyze a medium multi-zone office building's annual energy performance for the location and climate data of central Belgrade. The reason for the investigation is to evaluate the HVAC system's and HR unit's performance in order to conduct the most preferable heating and cooling solution (best case scenario) for the climate conditions of Belgrade city.

The aim was to determine the heating and cooling energy demand for preferable microclimatic conditions and offer methods for improvement. In this research the energy performance of a 300 m^2 single level office building with an energy efficient envelope was analyzed and evaluated. Since indoor occupant comfort has to be maintained; the temperature, lighting comfort, humidity, and air velocity were set in the simulation control for a sedentary work environment. Intervals of occupancy and HVAC operation were implemented in the multi-zone model. Finally, the average climate data was imported from Meteonorm 7 database for the location of central Belgrade [8].

Four HVAC systems were modelled and compared under the same conditions, referring to the climate data, internal loads, occupant schedules and energy efficient envelope with wall *U*-value of 0.25 W/m^2K and glazing *U*-value 1.0 W/m^2K. The HVAC system's and HR unit's performance was simulated in order to conduct the most preferable heating and cooling solution for the selected boundary conditions of indoor comfort parameters.

Methods

The admission of numerous aspects of interpretation plays a key role in energy performance assessment. A detailed energy simulation requires all phases of the project to be designed carefully and precisely, so the integrated parameters create an environment approximated to natural conditions. The interpolation of detailed hourly climate data is obligatory in the simulation, which is programmed to be conducted for an annual period in hourly time steps. The calibrated parametric model's construction properties, internal loads and HVAC system properties have to form a tight dependence, thus the results will present less deviation from real conditions. The influence of each factor can be examined extensively and systematically utilizing a dynamic energy simulation engine as EnergyPlus, which allows flexibility of the thermal model and its properties.

The HVAC system and HR unit was the primary topic of consideration, since the heating and cooling loads require the highest amount of energy on an annual period in office buildings. The investigation involves the calculation of the building energy performance of four HVAC system types tested on a medium office building model. Four multi-zone models with identical envelope, internal loads and occupancy schedules were constructed with the application of the following HVAC systems:

(1) *System 1*: Heat pump – air to air (Multi-zone model 1)
(2) *System 2*: Gas and electricity (Multi-zone model 2)
(3) *System 3*: Electrical (Multi-zone model 3)
(4) *System 4*: Fan coil – Rooftop unit with chiller and boiler (Multi-zone model 4)

The methodology used in the investigation includes the following:

– modelling – designing a multi-zone building model with an energy efficient envelope, internal loads, occupancy schedules and HVAC system,
– simulation – hourly time step calculation in EnergyPlus simulation engine, utilizing system thermodynamics and heat balance method, which operates with surface and air mass balance modules, and
– comparative analysis and evaluation of the results.

Results outline major criteria for improvement from a synthesized, comparative, and evaluative angle. The investigation concerns the following steps:

– designing a virtual single level multi-zone office building model according to the guidelines and functional disposition of office work spaces,
– implementation of climate and location data, envelope construction, internal loads and HVAC systems,
– run multiple simulations for an annual period,
– comparatively analyze and evaluate the annual energy performance of four multi-zone thermal models with different HVAC systems and assess the HVAC systems energy demand, and
– assessment of the HR unit's efficiency.

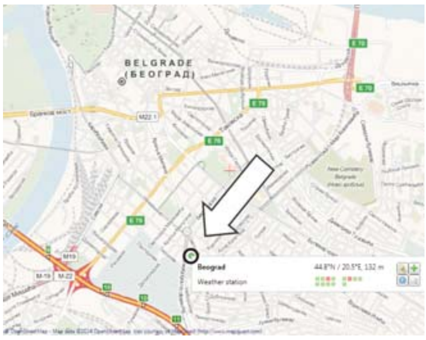
Materials and multi-zone building model

Location and climate data

The parametric model was constructed as a single level multi-zone office building model according to the functional disposition of office work spaces with an area of 300 m^2. The location and climate data were imported from Meteonorm 7 – global climatological database for central Belgrade, as shown in tab. 1. [8].

Table 1. Location data

Location data: central Belgrade
Program: Meteonorm 7
Latitude 44.810 deg.
Longitude 20.473 deg.
Altitude 132 m
Climatic zone: III, 3
Radiation model: Default (hour)
Temperature model: Default (hour)
Temperature: New period: 2000-2009



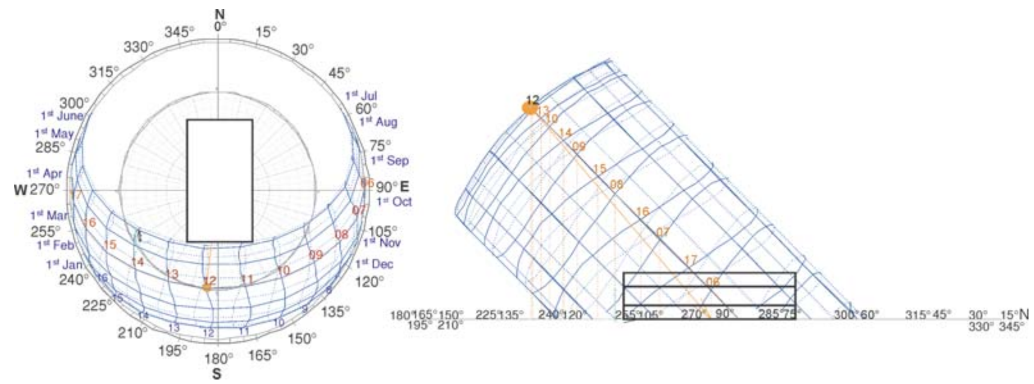


Figure 1. Annual Sun-path with building orientation

The monthly average values of the climate data and annual Sun-path with building orientation are shown in fig. 1. and tab. 2 in the appendix [8].

Modelling and simulation methodology

According to the model complexity and simulation process, four programs were used for this study, which are the following:
(1) Autodesk Revit Architecture 2011 – 3-D model design, function, and construction [9],
(2) Sketchup Make – Multi-zone thermal model construction [10],
(3) Open Studio – Integration of multi-zone thermal model properties; construction materials, internal loads, occupancy, and HVAC schedules [11], and
(4) EnergyPlus – energy simulation [12].

Complex dynamic simulation has been applied to determine detailed annual energy performance, since this type of simulation describes the function and behavior of a parametric analysis model. Dynamic simulations are run in time intervals in order to create a realistic environment for detailed investigation of the energy demand.

The investigation was conducted on a virtual medium single level free-standing multi-zone office building, where the offices are positioned towards East, South, and West separated by a central corridor. Each thermal zone was assigned with internal load properties typical for a medium office building. The thermal zones were formed and named according to their function in the building, as shown in tab. 3. The internal zone loads were set to typical medium office loads considering occupancy, electric equipment, and lighting.

Table 3. Thermal zones and spaces

Thermal zone	Space	Area [m^2]	Volume [m^3]	Thermal zone	Space	Area [m^2]	Volume [m^3]
Thermal zone 1	Office 1	48.27	168.95	Thermal zone 3	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
Thermal zone 2	Office 4	16.53	57.85	Thermal zone 4	Corridor	60.00	210.0
	Office 5	16.53	57.85		WC	12.50	43.75
Area sum [m^2]			300	Volume sum [m^3]			1050

Zone-temperature set points were included according to the space functions in the multi-zone building model. The HVAC systems were applied for identical multi-zone models, thus four models were created with identical function, internal loads and construction. Obtained results are comparatively analyzed in terms of energy specific intensity, [$kWha^{-1}$] and [$kWhm^{-2}a^{-1}$].

The annual heating and cooling demand and HVAC energy performance are explored through the following steps:

- development of a simulation base multi-zone 3-D model with assigned internal loads,
- export the multi-zone 3-D model to Open Studio in order to implement an energy efficient envelope, assign material properties, thermal zone properties and typical interior loads for offices,
- implement each HVAC system in a separate but identical multi-zone model,
- run multiple simulations in EnergyPlus on annual basis using the climate data from Meteonorm 7 (Belgrade climate data) and calculate zone heating and cooling demands,
- implement for each HVAC system a HR unit connected to the air loop outdoor air system, and
- evaluate the energy performance of the building and evaluate the HR unit's efficiency.

The thermostat schedules are presented in tab. 4.

Table 4. Thermostat schedules

Schedule	Date	Time	Temperature set point
Office cooling set-up schedule	01.05-30.09	Mon. to Fri. 7-18 h	24 °C
Office heating set-up schedule	01.10-30.04	Mon. to Fri. 7-18 h	21 °C

Table 5. Modified construction set properties

Exterior wall layers	Properties	Window layers	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 = 0.1016m 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		

The schedules for HVAC equipment operation, interior lights and occupancy intervals 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 selected. The modified envelope layers consider the insulation of exterior walls and application of efficient window construction (double glazing with low-E layer). Modified construction layers are shown in tab. 5, and envelope surface properties are shown in tab. 6.

Table 6. Surface properties

	Construction	Reflectance [–]	*U*-factor with film [$Wm^{-2}K^{-1}$]	*U*-factor no film [$Wm^{-2}K^{-1}$]
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 [$Wm^{-2}K^{-1}$]	Glass SHGC [–]	Glass visible transmittance [–]
		1.00	0.290	0.271

The building envelope and window to wall ratio is shown in tab. 7.

Table 7. Window-area, 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

HVAC system types and equipments

Four HVAC systems have been modelled according to the system type and supply fuel. The systems consist of the following supply and demand equipments assigned to each multi-zone model, as shown in tab. 8. The schemes of the four HVAC systems are show in the appendix. For detailed set-up of the HVAC systems' mechanical elements, professional sources were used [13, 14]

Building energy performance results and discussion

Primary simulation – without the HR unit

The simulation was performed for a period of one year, 8760 hours with hourly time steps. The primary simulations were run without the HR unit and the obtained results are shown below in fig. 2-9 as a proportional representation and annual sum of building energy demand. Numerical results are shown in tab. 9-12. The absolute values of monthly energy demands are shown from a proportional aspect for an annual period, in order to compare the energy demands of interior loads, fans, heating and cooling. In all four cases the highest annual energy demand was recorded for heating.

Table 8. HVAC system equipments

Equip.	System 1 – Heat pump (air to air)	System 2 – Gas and electricity
Supply equipment	1. Coil cooling DX single speed 2. Coil heating DX single speed 3. Coil heating electric 4. Variable speed fan 5. Set point manager single zone reheat	1. Coil cooling DX single speed (heat pump) 2. Coil heating (gas boiler) 3. Variable speed fan 4. Set point 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 terminalwith gas reheat
Equip.	System 3 – Electrical	System 4 – Fan coil
Supply equipment	1. Coil cooling DX single speed 2. Coil heating electric 3. Variable speed fan 4. Set point manager single zone reheat	1. Coil cooling water – Pump variable speed, electric chiller 2. Coil heating water – Pump variable speed, gas boiler 3. Variable speed fan 4. Set point manager single zone reheat
Demand equipment	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	Zone 1 – Air terminal single duct VAV with reheat Zone 2 – Air terminal single duct VAV with reheat Zone 3 –Air terminal single duct VAV with reheat Zone 4 –Air terminal single duct VAV with reheat

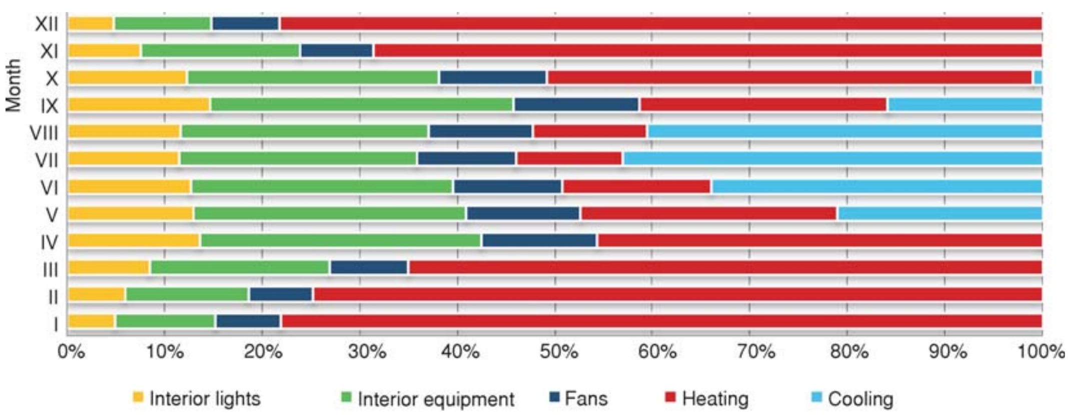


Figure 2. Monthly energy performance proportion – System 1 – Heat pump (air to air)
(for color image see journal web site)

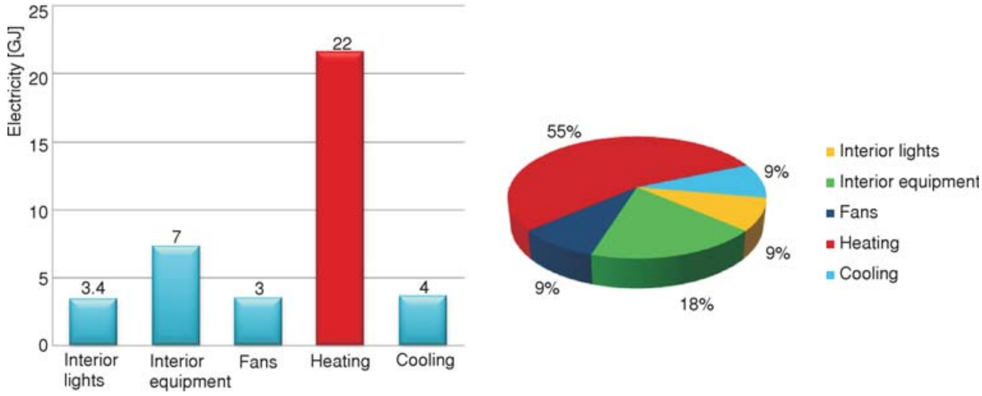


Figure 3. Annual energy demand – System 1 – Heat pump (air to air)
(for color image see journal web site)

For each multi-zone model the absolute value of interior lighting and equipment was set to constant intensity during working hours for every month, yet the proportional monthly energy demand presented a significant deviation. For system 1 (heat pump – air to air), fig. 2, in the summer period the constant loads (interior lights and equipment) were approximated to 40% of total monthly consumption, while the winter period presented close to 20%. The highest heating energy requirement was recorded for January, February, and December, nearly 78% of total monthly demands. In contrary, the peak demand for cooling was slightly above 40% in July.

The obtained heating load for the heat pump shows an annual energy demand of 22 GJ from total 39.4 GJ, which is 55% from total annual demand, fig. 3. Table 9 shows the annual demand and peak values for the heat pump – air to air without the HR unit. Nevertheless, the heating energy demand can be reasonably lowered, with the attachment of the HR unit to the outside air loop system, which will be elaborated in the following section.

The absolute value of interior lighting and equipment for system 2 (gas-electricity), fig. 4, presents only 2% of the energy requirement in the winter period, while in the summer period it rises to nearly 9%. The heating energy demand presented drastic values in the winter period with a peak demand of 92%. The peak value for cooling in the summer period reached close to 32%.

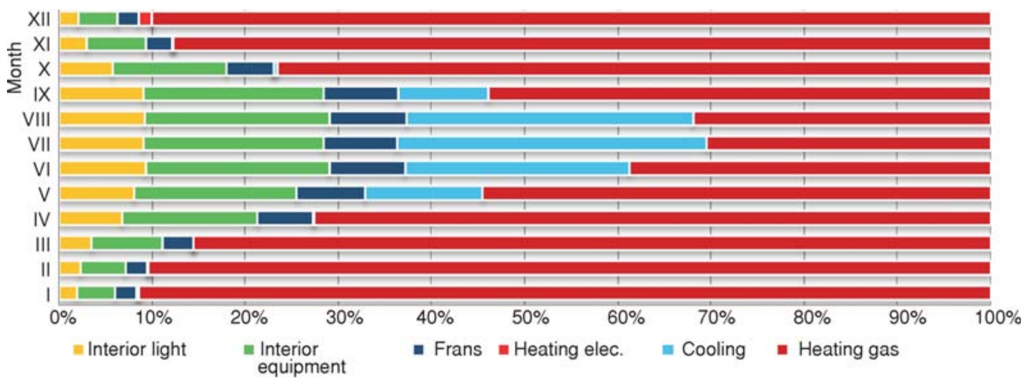


Figure 4. Monthly energy performance proportion – System 2 – Gas and electricity
(for color image see journal web site)

Table 9. Building energy performance – Heat pump (air to air)

	Int. light: elec. [MJ]	Int. eq.: elec. [MJ]	Fans: elec. [MJ]	Heating: elec. [MJ]	Cooling: elec. [MJ]
Annual sum	3,385	7,276	3,454	21,597	3,639
Min. of months	259	558	247	279	–
Max. of months	292	623	428	4,843	1,102

The heating load for system 2 supplied with gas and electricity requires the highest amount of energy among the four compared systems. The heating load is three times higher in comparison with the heat pump. The obtained heating load for system 2 (gas-electricity) shows an annual energy demand of 66 GJ from total 83.7 GJ, which is 79% from the total annual demand, fig. 5. Table 10 shows the annual demand and peak values for system 2 without the HR unit.

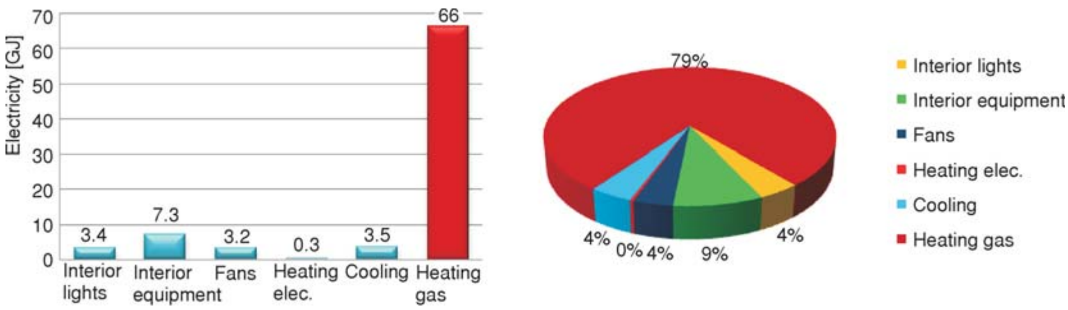


Figure 5. Annual energy demand – System 2 – Gas and electricity (for color image see journal web site)

Table 10. Building energy performance – Gas and electricity

	Int. light: elec. [MJ]	Int. eq.: elec. [MJ]	Fans: elec. [MJ]	Heating: elec. [MJ]	Cooling: elec. [MJ]
Annual sum	3,385	7,276	3,235	66,264	3,515
Min. of months	259	558	247	983	39
Max. of months	292	623	335	13,768	1,070

The monthly energy performance for system 3 (electrical) is presented in figs. 6 and 7.

The absolute values of internal loads for system 3 (electrical), fig. 6, show 2% of the energy requirement in the winter period, while in the summer period it rises nearly to 14%. The heating energy demand has shown a peak demand of 85% in January. The peak value for cooling in the summer period reached close to 15%, while the fans require from May until September close to 40% of total monthly energy.

The obtained heating load for system 3 (electrical) presented an annual energy demand of 43 GJ from total 64.4 GJ, which is 67% from the total annual demand, fig. 7. Table 11 shows the annual demand and peak values for system 3 without the HR unit.

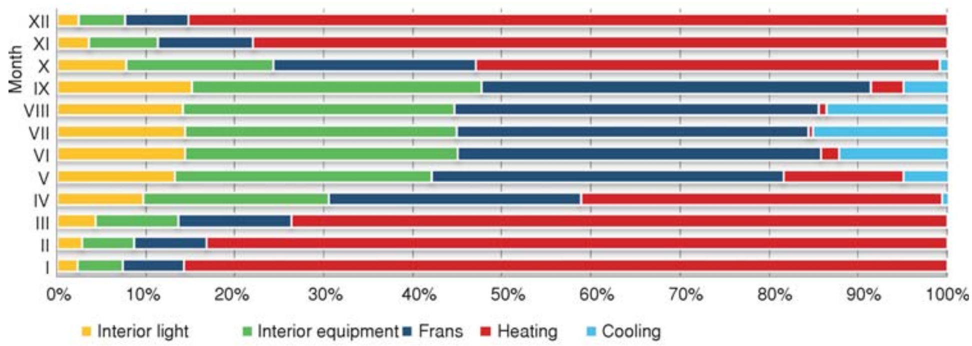


Figure 6. Monthly energy performance proportion – System 3 – Electrical
(for color image see journal web site)

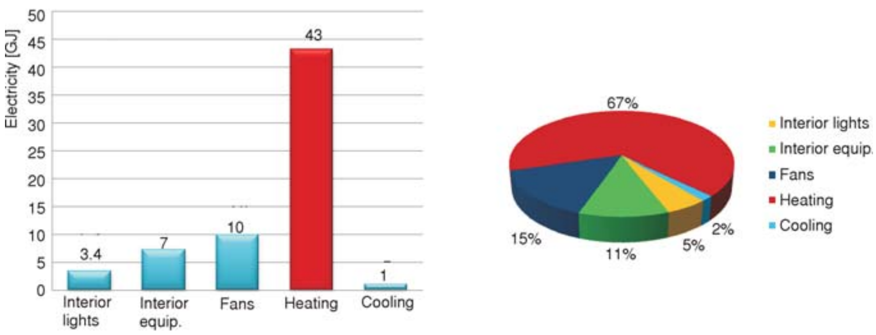


Figure 7. Annual energy demand – System 3 – Electrical
(for color image see journal web site)

Table 11. Building energy performance – Electricity – Electrical system

	Int. light: elec. [MJ]	Int. eq.: elec. [MJ]	Fans: elec. [MJ]	Heating: elec. [MJ]	Cooling: elec. [MJ]
Annual sum	3,385	7,276	9,880	43,158	1,076
Min. of months	259	558	766	11	–
Max. of months	292	623	859	10,572	308

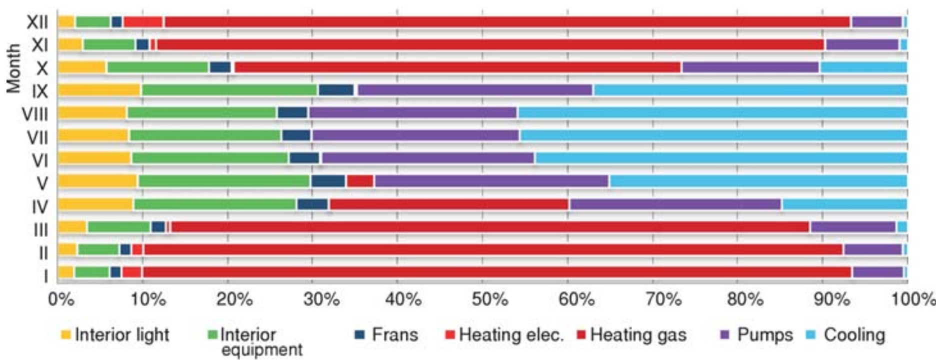


Figure 8. Monthly energy performance proportion – System 4 – Fan coil
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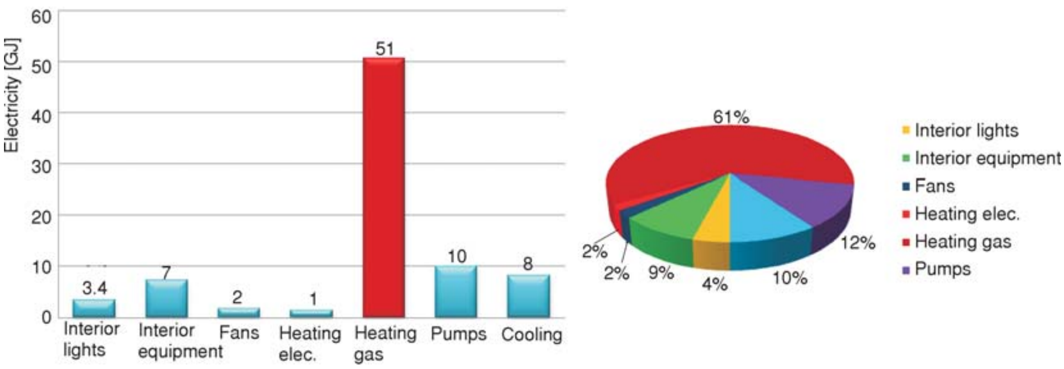

Figure 9. Annual energy demand – System 4 – Fan coil system (for color image see journal web site)

The absolute value of internal loads for system 4 (fan coil) presented 6% of the energy requirement in the winter period, while in the summer period it rises nearly to 30%. The heating energy demand has shown a peak demand of 83% in January. The peak value for cooling in the summer period reached close to 46%, while the fans require close to 24% of the total monthly energy.

The simulated heating load for system 4 (fan coil) resulted in an annual energy demand of 52 GJ from total 82.4 GJ, which is 61% from the total annual energy demand, fig. 9. The annual energy demand with peak values for system 4 is shown in tab. 12 without the HR unit.

Table 12. Building energy performance – Electricity – Fan coil system

	Int. light: elec. [MJ]	Int. eq.: elec. [MJ]	Fans: elec. [MJ]	Pumps: elec. [MJ]	Heating: gas [MJ]	Cooling: elec. [MJ]
Annual sum	3,385	7,276	1,752	10,039	52,079	8,150
Min. of months	259	558	121	787	–	60
Max. of months	292	623	217	904	12,438	1,594

The fan coil system has a higher energy demand since it operates with two coil loops; heating coil loop connected to the boiler and the cooling coil loop connected to the rooftop chiller. Both loops have a separate electric pump which has an energy demand of 10 GJ annually. The answer to the high heating demand of 52 GJ is the gas supplied boiler. In comparison with the previous gas heater, HVAC system 2, the result is lower for 14 GJ, although system 2 had one coil loop with only one variable speed pump in operation.

Evaluation and comparison of the HVAC systems' primary energy performance Secondary simulation – with HR unit

The second phase refers to the HR – Rotary Heat Exchanger unit's connection to the outdoor HVAC system air loop in EnergyPlus with the following properties shown in tab. 13.

Annual energy performance results of the four HVAC systems were converted into primary energy according to the HVAC systems' supply fuel and fuel production technology. The conversion factor for electricity, for the Serbian power plant supplied by "lignite" coal equals approximately $f_{prime} = 3.5$. The conversion factor for gas is $f_{prime} = 1.1$ [15]. The conver-

Table 13. HR – Rotary heat exchanger air to air sensible and latent

Supply air flow rate	Autosized
Sensible effectiveness at 75% heating air flow	0.81
Latent effectiveness at 75% heating air flow	0.73
Sensible effectiveness at 75% cooling air flow	0.82
Latent effectiveness at 75% cooling air flow	0.73
Heat exchanger type	Rotary

sion factor refers to the production technology and transportation efficiency of energy. Gas has a low conversion factor, because it is excavated on site and after minor treatment transported directly to the user. On the contrary, power plant using lignite coal for electricity production in Serbia operates with conversion factor between f_{prime} = 3.0-4.0. Table 14 shows the converted total annual primary energy demand for each HVAC system, applied to the identical multi-zone building models.

Table 14. Total annual primary energy demand of multi-zone office building

System 1 – Heat pump (air to air)	System 2 – Gas and electricity	System 3 – Electrical	System 4 – Fan coil
Primary energy without HR unit			
127 kWhm^2/a	124 kWhm^2/a	209 kWhm^2/a	218 kWhm^2/a
Σ 38,255 kWh/a	Σ 37,451 kWh/a	Σ 62,965 kWh/a	Σ 65,588 kWh/a
Primary energy with HR unit			
87 kWhm^2/a	84 kWhm^2/a	135 kWhm^2/a	151 kWhm^2/a
Σ 26,351 kWh/a	Σ 25,332 kWh/a	Σ 40,670 kWh/a	Σ 45,585 kWh/a
Primary energy reduction with HR unit			
31.5%	32.3%	35.4%	30.7%

The result for the gas supplied HVAC system, due to its very low conversion factor has the least primary energy demand of 37.45 MWh/a, close to the primary energy demand of the highly efficient heat pump supplied by electricity. The HR unit's efficiency shows a slight deviation among each system. Although the proportional deviation is low, the absolute deviation in significant. For example, as shown in tab. 14, the proportional deviation between the heat pump and the fan coil system is 0.8%, however the absolute deviation is approximately 20 MWh/a, 42%. Table 15 shows the primary energy demand for the heating and cooling loads and the percentage of these loads in comparison with the total annual energy performance.

Table 15. Annual heating and cooling loads primary energy

System 1 – Heat pump (air to air)	System 2 – Gas and electricity	System 3 – Electrical	System 4 – Fan coil
Heating and cooling demand without HR			
Σ 24.566 kWh/a	Σ 20,248 kWh/a	Σ 43,006 kWh/a	Σ 24,746 kWh/a
64% of the total energy requirement	54% of the total energy requirement	68% of the total energy requirement	38% of the total energy requirement
Heating and cooling demand with HR			
Σ 12.785 kWh/a	Σ 8,581 kWh/a	Σ 20,693 kWh/a	Σ 23,787 kWh/a
48% of the total energy requirement	34% of the total energy requirement	51% of the total energy requirement	32% of the total energy requirement

Heating and cooling demands without the HR unit show a relatively high percentage of 64% for the heat pump, 54% for the gas-electricity, 68% for the electrical system, and 38% for the fan coil. The importance of the HR unit is significant since it lowers these demands drastically, from 64% to 48% for the heat pump, from 54% to 34% for the gas-electricity and finally from 68% to 51% for the electrical system. The fan coil system was specific because the HVAC system operation requires a constant energy supply, so the heating and the cooling demand was lowered the least, from 38% to 32%.

The evaluation of the HVAC systems indicates that the most efficient system among the compared for heating and cooling would be the heat pump (air to air) and the gas-electricity, since the primary energy need for these systems with the HR unit application is approximately equal. However, the simulation presented that a multi-zone office building with heat pump HVAC system demands three times less heating energy, compared to the gas-electricity HVAC system from previous calculations, shown in tab. 9 and 10. In further research an economic evaluation will present a more detailed comparative overview of the mentioned systems.

The calculations also consider the HVAC systems' energy intensity as shown in tab. 16, without and with the application of the HR unit. This comparative analysis increases the importance of HR unit application, resulting in lower energy requierement for HVAC system operation.

Table 16. Utility use per total floor area

HVAC System	Without HR, annual HVAC energy demand [$kWhm^{-2}a^{-1}$]	With HR, annual HVAC energy demand [$kWhm^{-2}a^{-1}$]
Heat pump	21.15	15.56
Gas and electricity	6.65 electricity, 62.72 gas, Σ 69.37	6.21 electricity, 26.59 gas, Σ 32.8
Electrical	51.24	29.50
Fan coil	23.56 electricity, 48.36 gas, Σ 71.92	29.16 electricity, 31.91 gas, Σ 61.07

Table 17 shows the conversions from tab. 16 into primary energy for the operation of the four HVAC systems.

Table 17. Primary energy use for HVAC operation per total floor area

HVAC System	Without HR, HVAC energy intensity [$kWhm^{-2}a^{-1}$]	With HR, HVAC energy intensity [$kWhm^{-2}a^{-1}$]
Heat pump	74.03	54.46
Gas and electricity	23.28 electricity, 68.99 gas, Σ 92.27	21.73 electricity, 29.25 gas, Σ 50.98
Electrical	179.34	103.25
Fan coil	82.46 electricity, 53.19 gas, Σ 135.65	102.06 electricity, 35.10 gas, Σ 137.16

The heat pump HVAC system with HR unit requires the least annual energy for operation (15 kW/hm^2a, primary 54 kWh/m^2a), while the fan coil HVAC system with HR unit required the most (61 kWh/m^2a, primary 137 kWh/m^2a) among the four designed systems. From the comparative analysis the presented results indicate that for central Belgrade location and climate parameters a similar multi-zone office building with similar functional disposition, envelope construction and glazing properties requires the least amount of energy for the HVAC operation if the heat pump (air to air) system is applied. The analysis indicates that the most preferable solution for a medium office building between (200-400 m^2) would be the application of the heat pump (air to air) powered HVAC system with HR unit with an annual operating energy demand of 15.56 kWh/m^2a. Althought the climate parameters and internal loads are variable, the same method can be applied for further investigation.

Final remarks and conclusion

Dynamic energy performance simulations are useful in order to assess and analyze the energy demands of a building, underlining the importance of decision-making in the early stages of design. Therefore, engineering decisions in further stages of improvement and optimization can be precise.

The paper has elaborated a topic of applying the computational approach in evaluation of the annual energy performance on a multi-zone office building model with typical internal loads, in order to assess the total annual energy demand of the building and HVAC system operation. An evaluative study was conducted for the HR unit's performance in order to analyze its efficiency on an annual heating and cooling period. From the comparative analysis the presented results indicate that for central Belgrade location and climate a similar, according to the analyzed, multi-zone office building between (200-400 m^2) would have the most efficient preformance if the heat pump HVAC system with HR unit is applied, since the annual HVAC operational energy demand is approximately 15 kWh/m^2a. The heat pump HVAC system's energy intensity is significantly lower compared to the gas-electricity (33 kWh/m^2a), electrical (30 kWh/m^2a) and fan coil (61 kWh/m^2a) system from the simulations. The heat pump HVAC system's operational energy intensity per floor area is approximately 55% lower compared to the gas-electricity, 50% lower compared to the electrical and finally 74% lower compared to the fan coil.

Although the climate parameters, and internal loads are variable, the same method can be applied for further investigation. The paper has elaborated the importance of energy simulation in the first stages of a developing project.

Further investigations include validation of a similar office building for the same location. Future goals will be developed in the direction of comfort analysis to optimize annual building energy performance in the function of microclimatic conditions.

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Nomenclature

G-Gh – mean irradiance of global radiation horizontal, [Wm^{-2}]
G-Dh – mean irradiance of diffuse radiation horizontal, [Wm^{-2}]
N – cloud cover fraction, [–]
P – air pressure, [hPa]
Ta – air temperature, [°C]

Acronyms

DX – direct expansion, [–]
PIU – powered induction unit, [–]
RH – relative humidity, [%]
SHGC – solar heat gain coefficient, [–]
VAV – variable air volume, [–]

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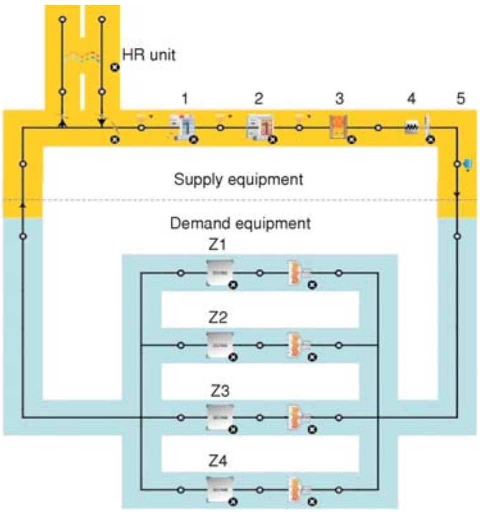
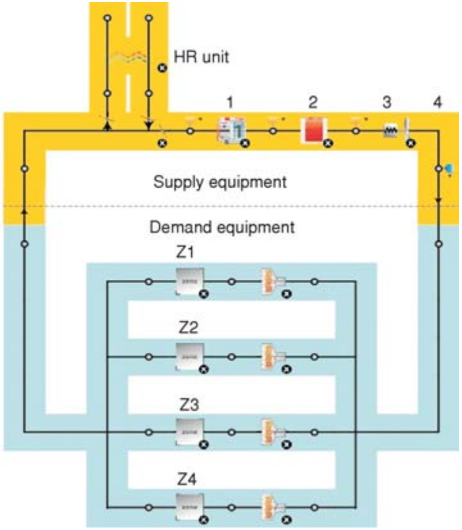
Appendix

Table 2. Climate data – Average values for central Belgrade

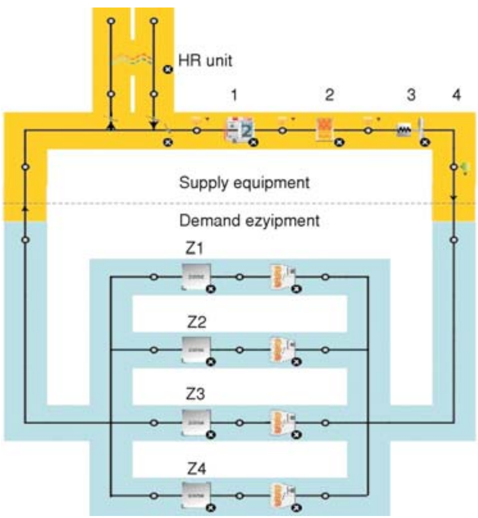
Month	*Ta* [°C]	*G-Gh* [Wm^{-2}]	*G-Dh* [Wm^{-2}]	*P* [Wm^{-2}]	*RH* [%]	*N*
Jan	1.6	52	30	997	75	6
Feb	3.7	88	47	998	69	6
March	8.5	137	65	998	60	5
Apr	13.6	184	85	998	58	5
May	18.8	232	117	998	58	5
June	21.7	250	122	998	60	5
July	23.6	259	104	999	57	4
Aug	23.4	233	97	998	59	4
Sept	17.8	172	76	998	66	5
Oct	13.7	113	53	998	70	5
Nov	8.4	63	35	998	71	5
Dec	2.9	47	25	997	77	6



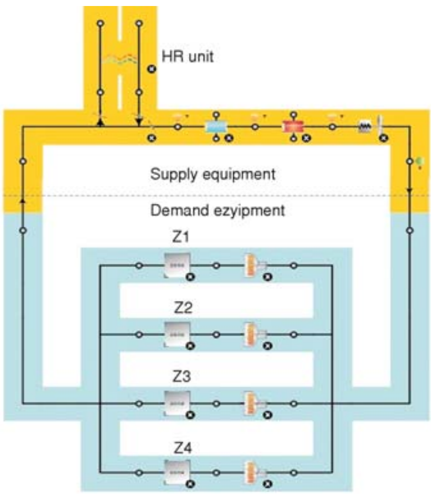
Scheme 1. System 1 – Heat pump (air to air)



Scheme 2. System 2 – Gas and electricity



Scheme 3. System 3 – Electrical



Scheme 4. System 4 – Fan coil

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