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Simulation Aided HVAC System Performance Assessment During Design Phase of an Office Building Complex

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Abstract: The investigation presents a strategic approach during the design process using advanced energy performance simulation technology. Team coordination and building performance efficiency during the design process is aided by conducting a performance-based assessment with comprehensive fully incorporated design, construction, energy, HVAC and annual building operation. Performance based decision making is demonstrated through an office building complex. The engineering decisions were based on performance enhancement and overall energy demand reduction, which was evaluated on an annual basis. The building envelope's dominant curtain wall system was analyzed in detail in order to demonstrate qualitative energy performance improvement. VAV and DOAS HVAC systems' annual energy performance was estimated and evaluated from the aspect of end-use energy.

Keywords: BSIM, building performance, energy simulation, VAV system, DOAS system, EnergyPlus

1. Introduction

The investigation covers the energetic and operational energy demand analysis of a 23,205 Sqm office building complex (Ferrero, Lenta, Monetti, Fabrizio, & Filippi, 2015). Operational energy demands and HVAC system operation were analyzed in detail using complex input datasets: climatic database, building structure, thermal loads, occupancy and HVAC system documentation. Various design alternatives were used to select the most preferable curtain-wall structure. The calculations were performed with detailed dynamic energy simulation in EnergyPlus (Nguyen, Reiter, & Rigo, 2014) engine.

Our previous investigations were performed on existing buildings and their energy refurbishment processes (Harmathy, Magyar, & Folić, 2016; Harmathy & Murgul, 2016). Teams have demonstrated various approaches in energy analysis of office buildings using simulation techniques (Harmathy, Kontra, Murgul, & Magyar, 2017; HARMATHY, URBANCL, GORIČANEC, & MAGYAR).

Our task was to justify which curtain-wall window structure would be the most preferable from the energy performance aspect, and to demonstrate which is the most appropriate window type contributing to higher energy efficiency of the building. During the investigation according to the building's geometry the massing of the building contributed significantly to its energy performance. We evaluated the influence of the curtain-wall structure on the heating and cooling energy requirements on an annual basis, from which we determined the annual energy savings. The report includes selecting the right facade glass structure that meets the energy and cost optimum requirements. Furthermore, two types of HVAC systems were simulated in order to assess and evaluate their annual end use energy consumption in order to hold decision-making in the early design phases of the energy strategy (Cabeza, Rincón, Vilariño, Pérez, & Castell, 2014).

2. Research Focus and Methodology

During the energy performance analysis, we focused on the following:

- Building simulation and determination of energy demands
- Determining detailed heating and cooling energy requirements
- Analysis of thermal load alternatives

- Influence of internal heat loads on the annual energy balance
- Determining the energy influence of the glass structure annually
- Analyzing the effect of different curtain wall systems' thermal properties
- HVAC system simulation and end use energy determination of the project
- Total energy savings potential

The virtual environment was created in EnergyPlus software where the simulation was performed according to the calculation models from the EnergyPlus Engineering documentation (Martinaitis, Zavadskas, Motuzienė, & Vilutienė, 2015). The geometric thermal model was created in Sketchup (Chopra, Town, & Pichereau, 2012) and the data were imported in OpenStudio (Guglielmetti, Macumber, & Long, 2011) software.

3. Dynamic Simulation Input Parameters

3.1 Weather Data – Climatological Data Sets

The climatic data was used from the Meteonorm (Wernet et al., 2016) Swiss global database. The meteorological data package for Budapest contained more than 100,000 data. In the simulation process 30 year hourly averages were applied. In the dynamic simulation we used the following climatic data; air temperature, relative humidity, direct and indirect solar radiation, pressure, wind direction and wind speed.

The weather data for Budapest were used from the data packages of ASHRAE Climate Design Conditions (Aijazi & Brager, 2018; Spitler & Southard, 2016) which are shown in Table 1. Depending on the size and complexity of the building, we divided the model into 22 thermal zones. The energy zone allocation by area and volume is shown in Table 2. The 3D model of the boundary surface model and the thermal zone model is shown in Figure 1.

3.2 Building Envelope Thermal Properties

The building structure and layers were used in the thermal simulation according to the design and construction documentation. The objective was to analyses and simulate the building envelope's dual pane glass construction on the annual building energy performance.

Table 1: Weather file for BUDAORS, HUNGARY (WMO: 128380) from ASHRAE Climate Design Conditions

<table>
<tr><td colspan="2">Lat:47.45N</td><td colspan="2">Long:18.97E</td><td colspan="2">Elev:132</td><td colspan="3">StdP: 99.75</td><td colspan="3">Time zone:1.00</td><td colspan="4">Period:82-92</td></tr>
<tr><td colspan="16">Annual Heating and Humidification Design Conditions</td></tr>
<tr><td rowspan="3">Coldest Month</td><td colspan="2" rowspan="2">Heating DB</td><td colspan="6">Humidification DP/MCDB and HR</td><td colspan="4">Coldest month WS/MCDB</td><td colspan="2" rowspan="2">MCWS/PCWD to 99.6% DB</td><td rowspan="2"></td></tr>
<tr><td colspan="3">99.6%</td><td colspan="3">99%</td><td colspan="2">0.4%</td><td colspan="2">1%</td></tr>
<tr><td>99.6%</td><td>99%</td><td>DP</td><td>HR</td><td>MCDB</td><td>DP</td><td>HR</td><td>MCDB</td><td>WS</td><td>MCDB</td><td>WS</td><td>MCDB</td><td>MCWS</td><td>PCWD</td><td></td></tr>
<tr><td>1</td><td>-11.2</td><td>-9.0</td><td>-14.4</td><td>1.1</td><td>-9.8</td><td>-12.3</td><td>1.3</td><td>-7.3</td><td>18.0</td><td>-0.9</td><td>16.6</td><td>0.7</td><td>1.9</td><td>270</td><td></td></tr>
<tr><td colspan="16">Annual Cooling, Dehumidification, and Enthalpy Design Conditions</td></tr>
<tr><td rowspan="3">Hottest Month</td><td rowspan="3">Hottest Month DB Range</td><td colspan="6">Cooling DB/MCWB</td><td colspan="6">Evaporation WB/MCDB</td><td colspan="2" rowspan="2">MCWS/PCWD to 0.4% DB</td></tr>
<tr><td colspan="2">0.4%</td><td colspan="2">1%</td><td colspan="2">2%</td><td colspan="2">0.4%</td><td colspan="2">1%</td><td colspan="2">2%</td></tr>
<tr><td>DB</td><td>MCWB</td><td>DB</td><td>MCWB</td><td>DB</td><td>MCWB</td><td>WB</td><td>MCDB</td><td>WB</td><td>MCDB</td><td>WB</td><td>MCDB</td><td>MCWS</td><td>PCWD</td></tr>
<tr><td>7</td><td>10.3</td><td>31.0</td><td>20.1</td><td>29.3</td><td>19.7</td><td>27.8</td><td>19.2</td><td>21.3</td><td>28.9</td><td>20.5</td><td>27.5</td><td>19.8</td><td>26.1</td><td>2.9</td><td>180</td></tr>
<tr><td colspan="9">Dehumidification DP/MCDB and HR</td><td colspan="6">Enthalpy/MCDB</td><td rowspan="3">Hours 8 to 4 and 12.8/20.6</td></tr>
<tr><td colspan="3">0.4%</td><td colspan="3">1%</td><td colspan="3">2%</td><td colspan="2">0.4%</td><td colspan="2">1%</td><td colspan="2">2%</td></tr>
<tr><td>DP</td><td>HR</td><td>MCDB</td><td>DP</td><td>HR</td><td>MCDB</td><td>DP</td><td>HR</td><td>MCDB</td><td>Enth</td><td>MCDB</td><td>Enth</td><td>MCDB</td><td>Enth</td><td>MCDB</td></tr>
<tr><td>18.6</td><td>13.7</td><td>24.3</td><td>17.9</td><td>13.1</td><td>23.6</td><td>17.3</td><td>12.5</td><td>23.0</td><td>62.1</td><td>28.9</td><td>59.4</td><td>27.9</td><td>56.9</td><td>26.1</td><td>923</td></tr>
<tr><td colspan="16">Extreme Annual Design Conditions</td></tr>
<tr><td colspan="3" rowspan="2">Extreme Annual WS</td><td rowspan="2">Extreme Max WB</td><td colspan="4">Extreme Annual DB</td><td colspan="8">n-Year Return Period Values of Extreme DB</td></tr>
<tr><td colspan="2">Mean</td><td colspan="2">Stand.deviation</td><td colspan="2">n=5 years</td><td colspan="2">n=10 years</td><td colspan="2">n=20 years</td><td colspan="2">n=50 years</td></tr>
</table>

1%	2.5%	5%		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
13.9	11.6	9.3	24.3	-16.3	33.5	5.1	1.4	-19.9	34.5	-22.9	35.3	-25.8	36.1	-29.4	37.1
Monthly Climatic Design Conditions															
			Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperatures, Degree-Days and Degree-Hours		Tavg	10.6	-0.3	1.0	5.6	11.2	16.2	18.2	21.1	20.5	16.9	10.7	4.0	1.5
		Sd		4.86	4.66	4.47	3.47	3.27	3.04	2.99	3.20	3.06	3.98	3.79	4.18
		HDD10.0	1236	319	253	147	27	2	0	0	0	1	38	182	266
		HDD18.3	3072	577	486	396	216	81	38	9	16	64	236	431	523
		CDD10.0	1452	0	1	9	62	193	247	344	326	206	62	2	1
		CDD18.3	246	0	0	0	1	13	34	95	83	19	0	0	0
		CDH23.3	2089	0	0	0	4	101	276	860	698	149	2	0	0
		CDH26.7	573	0	0	0	0	14	55	272	211	22	0	0	0
Precipitation		PrecAvg	560	38	34	32	43	59	67	49	51	41	38	61	46
		PrecMax	823	78	136	59	83	128	141	106	114	114	154	173	120
		PrecMin	399	2	4	2	17	1	18	19	5	1	2	14	1
		PrecSD	112.1	19.6	29.5	17.2	18.0	35.0	32.9	25.4	32.1	28.1	40.1	48.0	28.3
Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures		0.4%	DB	10.5	16.3	21.3	24.3	28.8	30.3	33.2	32.4	29.3	23.1	15.5	14.4
			MCWB	7.0	10.2	13.0	15.3	17.7	20.2	20.3	20.5	19.2	16.1	11.6	10.8
		2%	DB	8.6	12.0	17.0	21.7	25.9	28.2	31.4	30.8	26.9	20.9	12.0	11.2
			MCWB	6.3	7.9	10.6	13.7	17.1	20.1	20.5	19.7	18.1	15.2	9.2	8.8

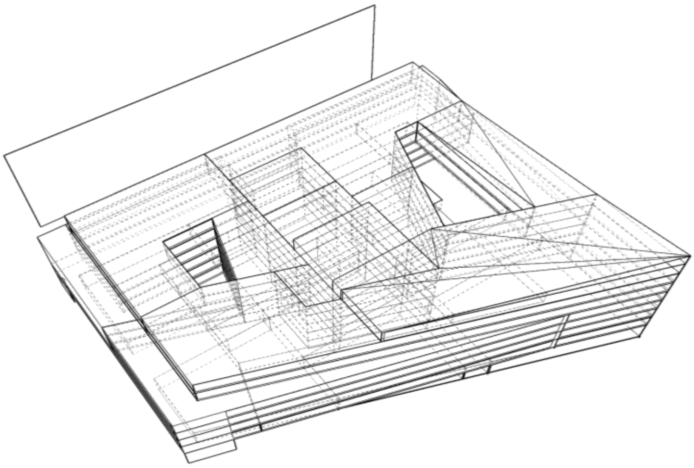
	5%	DB	7.4	8.8	14.6	19.6	24.1	26.4	29.7	29.1	25.1	18.8	10.3	9.1
		MCWB	5.4	5.7	9.5	13.0	16.7	18.9	20.0	19.5	17.8	13.6	8.1	6.9
	10%	DB	5.7	6.6	12.4	17.5	22.4	24.7	28.0	27.4	23.1	16.9	9.2	7.2
		MCWB	4.0	4.4	8.2	11.9	15.9	17.9	19.2	18.9	16.7	12.6	7.5	5.4
Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures	0.4%	WB	7.5	10.6	13.9	16.0	19.0	21.6	22.7	22.0	19.8	17.0	12.1	11.2
		MCDB	9.8	15.8	20.3	22.6	25.4	28.3	29.9	29.3	26.3	21.2	14.2	14.8
	2%	WB	6.6	8.1	11.2	14.3	18.0	20.7	21.4	21.1	19.1	15.5	9.6	8.8
		MCDB	8.4	11.5	15.9	20.2	24.3	27.0	29.4	28.9	25.8	19.9	11.1	10.9
	5%	WB	5.6	6.1	9.9	13.3	17.2	19.6	20.6	20.2	18.1	14.4	8.6	7.2
		MCDB	7.2	8.2	13.9	18.7	22.6	25.1	27.9	27.3	23.8	17.9	9.8	9.1
	10%	WB	4.2	4.7	8.6	12.3	16.4	18.6	19.9	19.5	17.2	13.2	7.6	5.5
		MCDB	5.6	6.5	12.0	16.8	21.4	23.5	26.3	25.8	22.1	16.1	9.0	7.1
Mean Daily Temperature Range		MDBR	5.0	6.3	8.1	8.8	9.1	9.0	10.3	10.1	10.2	9.2	6.4	4.8
	5% DB	MCDBR	6.7	10.8	12.4	12.4	12.3	12.4	13.4	13.4	13.0	12.3	8.2	6.8
		MCWBR	4.8	7.1	7.4	6.2	5.2	5.3	4.7	5.0	5.5	6.9	5.8	4.8
	5% WB	MCDBR	6.0	9.3	11.3	11.0	10.5	11.3	11.9	11.7	12.2	10.8	6.9	7.0
		MCWBR	4.5	6.4	7.0	5.9	4.8	5.3	4.6	4.6	5.5	6.9	5.8	4.8
Clear Sky Solar Irradiance	taub		0.330	0.355	0.376	0.377	0.378	0.388	0.391	0.396	0.376	0.357	0.354	0.332
	taud		2.453	2.302	2.299	2.283	2.266	2.239	2.275	2.286	2.366	2.461	2.464	2.482
	Ebn,noon		747	794	838	874	884	875	867	845	829	789	709	699

	Edn,noon	67	94	110	123	130	134	128	121	102	80	67	59

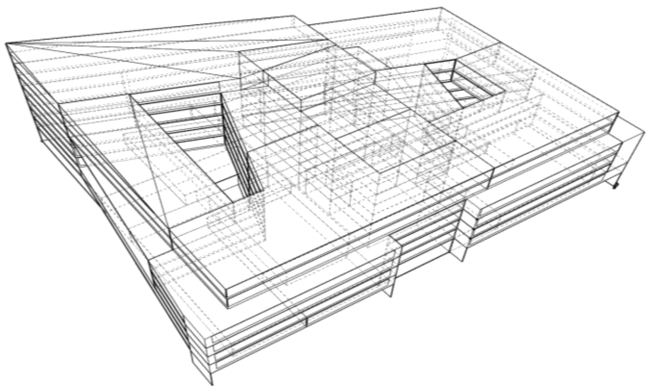
Table 2: Thermal zoning with area and volume

Thermal zone		Area [m^2]	Volume [m^3]
1	Open Office North 0	1425.15	6595.03
2	Open Office North 2	1278.78	3580.57
3	Open Office North 3	1278.78	3580.57
4	Open Office North 4	1155.29	3234.81
5	Open Office North 5	1161.40	3251.92
6	Open Office North 6	1161.40	3251.92
7	Open Office South 0	1576.57	6936.89
8	Open Office South 1	3402.77	10208.32
9	Open Office South 2	1432.48	4010.94
10	Open Office South 3	1432.48	4010.94
11	Open Office South 4	1432.48	4010.94
12	Open Office South 5	1519.52	4254.66
13	Open Office South 6	1519.52	4653.65
14	Open Office South 7	690.57	2386.66
15	Sanitary & Communication 0	390.75	1904.55
16	Sanitary & Communication 1	317.60	952.80
17	Sanitary & Communication 2	379.35	1062.18
18	Sanitary & Communication 3	379.35	1062.18
19	Sanitary & Communication 4	379.35	1062.18
20	Sanitary & Communication 5	379.35	1062.18
21	Sanitary & Communication 6	379.35	1062.18
22	Sanitary & Communication 7	132.30	370.44

	Total	23204.57	72506.51



(a)



(b)

Fig. 1: 3D thermal zone model

The building envelope's glass structure consisted of three glass structure types of which all are Argon filled, where under glazing A1 two different glass structures are applied according to project documentation:

- Glazing A1; U-Factor = 1.40 W/m2K, SHGC1= 0.4, SHGC2= 0.3, Glass Visible Transmittance1 = 0.70 with inner pane shading and Argon gas (Southern facade), Glass Visible Transmittance2 = 0.70 without inner pane shading.
- Glazing A2; U-Factor = 1.40 W/m2K, SHGC= 0.5, Glass Visible Transmittance = 0.73 (East and West orientation)
- Glazing A3; U-Factor = 1.40 W/m2K, SHGC= 0.6, Glass Visible Transmittance = 0.80 (North orientation)

The focus was on the structural and energetic performance of the facade glazing. The use of adequate glazing is of utmost importance for efficient energy reduction and user comfort. Choosing the right glass structure depends from; building's type and function, the building floor area, window to wall ratio, facade orientation, internal heat loads, building location and climate zone. The listed parameters all affect the efficiency of the glass structure, building on the energy of the building. We investigated the influence of the heat transfer factor (U), the solar factor (g) and the light transmission factor (τ) on the yearly energy requirements and user comfort of the building.

3.3 Thermal comfort demand and building operation data

The energy simulation allows detailed analysis of building operation according to schedules. Its significance lies in the fact that we can investigate the energy and heat loads of a building according to various time dependant scenarios. With energy simulation, we calculated the building's energy demand annually using the following data:

- Heating period (indoor air temperature):

Minimum indoor air temperature was 20°C during permanently occupied periods.

Outside working hours the maximum allowed temperature fall was 4°C.

The heating system operates with an automatic indoor air temperature sensor setting.

- Cooling period (indoor air temperature):

Maximum indoor air temperature was 26°C during permanently occupied periods.

Outside working hours the cooling system is not operating. The cooling system operates with an automatic indoor air temperature sensor setting.

In both periods, the perimeter values of air temperatures were maintained daily in 10 hour intervals (8-18h). In case changes in occupancy schedules of the building, number of people and work hours, the energy demands will change. The results of the energy simulation apply only to the specified 10 hours working time and to the perimeter values of the specified air temperature. Air change rate and specified air volume in thermal zones was calculated according to equation 1 where n is the number of people and A is the area in m2.

$$q_{tot} = n \times 25{,}2 + A \times 2{,}52$$

$$q_{tot} = 2520 \times 25{,}2 + 21400 \times 2{,}52$$

$$q_{tot} = 117432 \text{ m}^3/\text{h} \qquad \text{Eq. (1)}$$

For the office spaces 0.46 ach was assumed. In the simulation we counted 0.8 1/h air change was the maximum intensity during working hours. During unoccupied periods the air change rate was 0.1 1/h. The intensity of air exchange depends on working time. From 7 to 18 hours constant air volume was estimated.

3.4 Internal loads - heat sources

Internal heat loads are the thermal load delivered by users and office equipment (electrical equipment). Based on the functional “open office” disposition of spaces, the number of people occupants per floor was estimated. Table 3 shows the number of occupants per floor area. The internal gains were taken into consideration as constant loads for all 3 scenarios in the simulation to estimate adequate heating and cooling requirements of the building.

In case of occupant heat gain, 120W of constant heat load was calculated in the function of work hours. A total of 2520 PC's were assumed in the building, where 150W of heat load was assumed per PC in the function of work hours. The building occupancy intensity is presented in Figure 2. The occupied period is shown on the x axis, where the highest intensity is between 8-12h and 13-17h. Lunch break between 12-13h was included respectively.

Table 3: Occupancy per floor

Level	No. of occupants	Area [m²]	m² / person
ground floor	230	2000	8,7
1	450	3766	8,4
2	350	2995	8,5
3	350	2995	8,5
4	350	2995	8,5
5	350	2937	8,4
6	350	2937	8,4
7	90	777	8,6

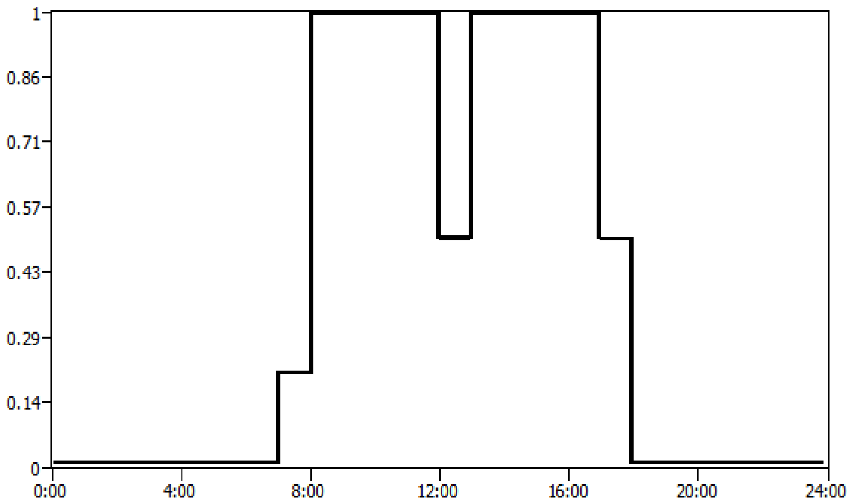


Fig. 2: Building occupancy schedule

4. Energy Performance Results

4.1 Annual energy demands for heating and cooling

With the energy simulation run-time of 8760 hours annual heating and cooling energy demands were determined for two operational scenarios:

- Permanent maximum heat loads – entire building is occupied during working hours
- Without internal heat loads – estimation of internal loads influence on the energy performance

Particular emphasis was placed on the curtain wall's glass structure and its energy performance. The heating and cooling energy requirements with different grazing types from the simulations are shown in Table 3 and Figure 3. The energy demands were classified according to the parameters of the facade glass structure. Table 4 shows the percentage deviation of the aggregate annual energy demand. Table 5 summarizes active and passive heat gains and losses. The highlighted vales are considering the heat addition and heat removal via the glazing structure.

Table 4: Annual energy demands for heating and cooling

Curtain wall glazing properties	Heating [MWh/a]	Cooling [MWh/a]	Heating per m2 [MWh/m^2/a]	Cooling per m2 [MWh/m^2/a]
With constant maximum internal heat loads				
A1 g1=0,4; g2=0,3	1228	658	53	28
A2 g=0,5	1184	800	51	34
A3 g=0,6	1151	941	49	40
Without internal heat loads				
A1 g1=0,4; g2=0,3	1557	60	67	3
A2 g=0,5	1475	138	63	6
A3 g=0,6	1415	228	61	10

Table 5: Annual energy demands percentual deviation

no.	Total energy [MWh/a]	Percentual reduction [%]	Reduced energy [MWh/a]
A1	1886	9,8% according to A3 5% according to A2	206 98
A2	1984	5% according to A3	108
A3	2092	0%	0

Table 6: Annual heat gains and losses per category

Thermal zone	HVAC Zone Eq & Other Sensible Air Heating [kWh]	HVAC Zone Eq & Other Sensible Air Cooling [kWh]	People Sensible Heat Addition [kWh]	Lights Sensible Heat Addition [kWh]	Equipment Sensible Heat Addition [kWh]	A1 Window Heat Addition [kWh]	A2 Window Heat Addition [kWh]	A3 Window Heat Addition [kWh]	Infiltration Heat Addition [kWh]	Opaque Surface Conduction and Other Heat Addition [kWh]	Window Heat Removal [kWh]	Infiltration Heat Removal [kWh]	Opaque Surface Conduction and Other Heat Removal [kWh]
1	26.76	-11.08	29.75	38.72	56.26	53.07	68.77	88.25	2.11	0.00	-38.23	-76.20	-81.17
2	13.79	-31.44	25.40	34.74	50.49	19.51	29.25	38.54	1.34	0.00	-26.87	-62.14	-24.81
3	14.38	-34.03	25.37	34.74	50.49	20.53	30.96	40.82	1.32	0.00	-27.19	-62.35	-23.26
4	13.61	-32.50	22.91	31.39	45.61	20.35	30.43	40.26	1.18	0.00	-24.61	-56.47	-21.47
5	15.01	-32.64	23.10	31.55	45.85	23.59	39.99	52.40	1.18	0.00	-29.61	-56.60	-21.42
6	17.25	-35.22	23.11	31.55	45.85	31.69	53.44	69.57	1.16	0.00	-30.95	-56.63	-27.82
7	23.14	-15.36	32.46	42.83	62.24	102.7	131.3	167.86	2.27	0.00	-35.27	-84.46	-130.5
8	33.85	-64.19	68.03	92.45	134.3	82.55	112.2	144.60	3.82	0.01	-46.54	-166.7	-137.5
9	12.77	-41.53	28.10	38.92	56.55	52.65	74.60	96.58	1.49	0.00	-34.48	-71.05	-43.42
10	12.89	-48.31	27.99	38.92	56.55	51.32	72.73	94.44	1.46	0.00	-35.65	-71.69	-33.47
11	13.61	-49.50	28.01	38.92	56.55	51.35	72.62	94.35	1.45	0.01	-36.07	-71.73	-32.59
12	16.14	-49.03	29.85	41.28	59.99	56.57	92.45	119.45	1.53	0.00	-41.60	-75.59	-39.12
13	20.11	-57.86	29.87	41.28	59.99	73.24	119.5	153.95	1.54	0.00	-49.56	-77.99	-40.62
14	10.67	-28.28	13.57	18.76	27.26	42.61	68.46	88.34	0.72	0.00	-26.84	-37.07	-21.40
15	130.94	-0.70	6.51	10.25	2.21	0	0	0	4.82	6.72	0.00	-160.7	0
16	114.74	-1.28	4.29	7.06	0.54	0	0	0	2.61	10.87	0.00	-138.8	0

17	137.03	-1.99	5.10	8.43	0.64	0	0	0	2.61	14.72	0.00	-166.5	0
18	136.36	-2.22	5.09	8.43	0.64	0	0	0	2.42	17.38	0.00	-168.1	0
19	136.63	-2.27	5.09	8.43	0.64	0	0	0	2.36	17.85	0.00	-168.7	0
20	137.65	-2.28	5.09	8.43	0.64	0	0	0	2.33	17.20	0.00	-169.0	0
21	139.28	-2.32	5.08	8.43	0.64	0	0	0	2.30	16.27	0.00	-169.6	0
22	50.67	-0.72	1.78	2.94	0.22	0	0	0	0.89	3.03	0.00	-58.80	0
Total Facility	1227.2	-544	445.28	618.33	814.16	681.66	996.66	1289.16	42.78	103.89	-483.3	-2226	-678.6

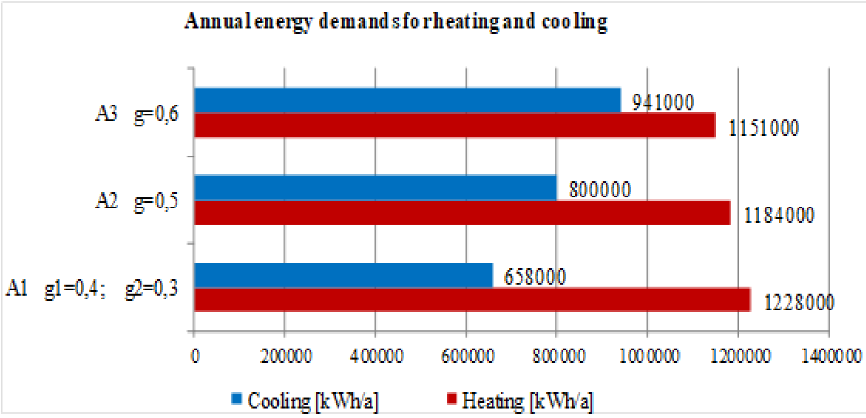


Fig. 3: Annual energy demands for heating and cooling

4.2 HVAC system energy performance simulation

Following the heating and cooling demand assessment according to adequate glazing assignment two of the following HVAC systems were simulated in order to assess their annual operating performance:

- HVAC System 1: Variable air volume (VAV) System with reheat
- HVAC System 1: Dedicated outdoor air system (DOAS) with fan-coil units (FCU)

The following table 6 shows the end energy uses for the VAV System with reheat and table 7 the DOAS FC system’s energy end use. Table 8 shows the annual electricity consumption of interior lighting and equipment.

Table 6: Annual end energy uses per category for VAV system

	Electricity [GJ]	Natural Gas [GJ]	Water [m3]
Heating	0.00	4843.80	0.00
Cooling	859.74	0.00	0.00
Fans	451.20	0.00	0.00
Pumps	724.35	0.00	0.00
Heat Rejection	25.27	0.00	3864.90
Total End Uses	2060.55	4843.80	3864.90

Table 7: Annual end energy uses per category for DOAS FC system

	Electricity [GJ]	Natural Gas [GJ]
Heating	161.64	930.45
Cooling	803.35	0.00
Fans	500.43	0.00
Total End Uses	1465.42	930.45

The electricity end energy use for the VAV system is in total resulted in 2060 GJ/a or 572 MWh/a, while the DOAS system performed with 1465 GJ/a or 407 MWh. The electricity reduction in operation of the DOAS system was 28.8% less compared to VAV. However, the natural gas reduction demonstrated high reduction percentage of 80.7%.

Table 8: Annual end uses per interior lighting and equipment

	Electricity [GJ]
Interior Lighting	2226.45
Interior Equipment	2931.12

5. Conclusion

The investigation presented that the energy demand could be influenced by the selection of adequate glazing type which can be determined by analyzing the curtain wall's influence on the total energy demand as function dependent. Findings indicated that for an office building with high internal heat gains can lower its heating demands by selecting glazing in wider SHGC interval from 0.3 to 0.6. The changes between the total energy demand (heating and cooling) scenarios for the three simulated glazing types was max. 9.8% on annual basis. However, investment in glazing with more efficient low-E layers is higher. Nevertheless, cooling should be taken in account seriously since the deviation was 30%. It was concluded that high energy reduction can be achieved according to the HVAC system operation. According to the findings the electricity reduction in operation of the DOAS system was 28.8% less compared to VAV. However, the natural gas reduction demonstrated even higher reduction of 80.7%.

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