

# Analysis and visualization of EPC data and development of innovative energy service

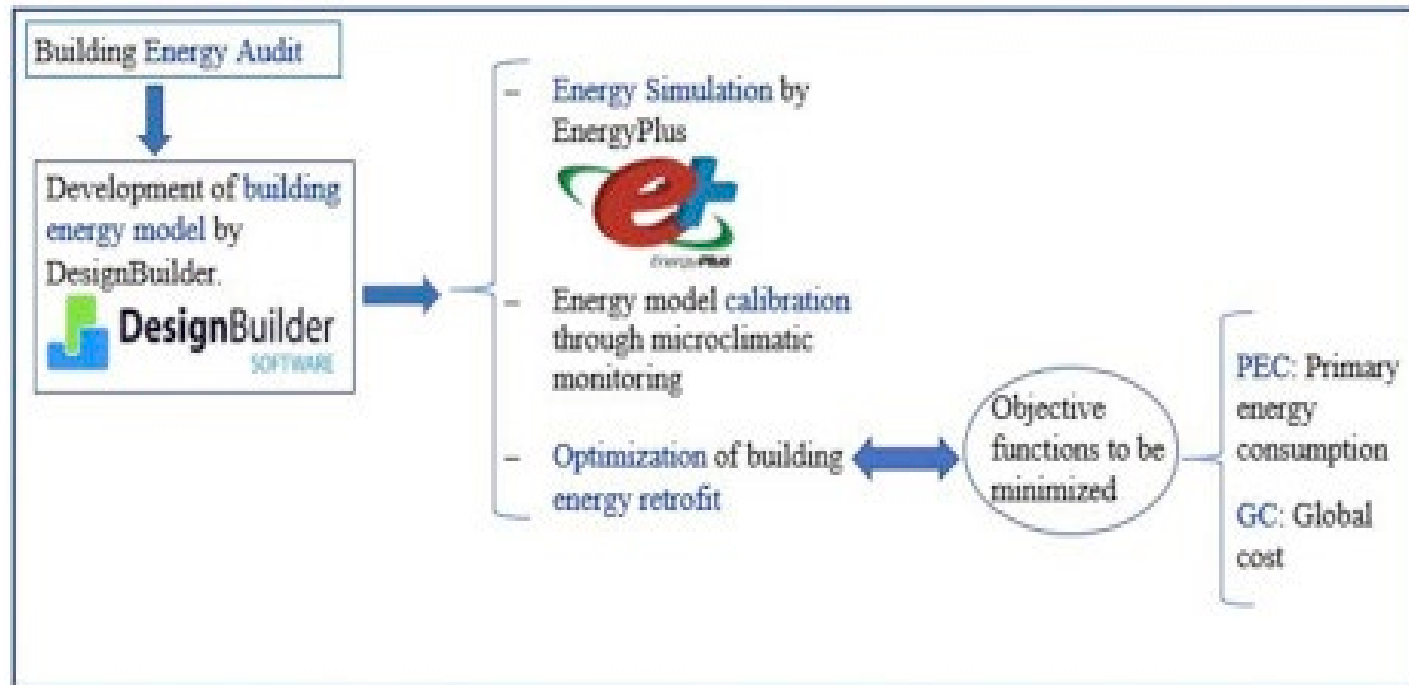
Calibration of dynamic energy consumption model with real data

**Denis Dergestin**

Consultant at Energy institute Hrvoje Požar

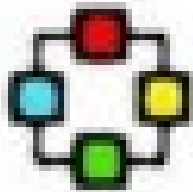
# What is Building Model Calibration?

- Process of **improving the accuracy of Building Energy Model simulation** to reflect the as-built status and actual operating conditions.



Source: A real industrial building: Modeling, calibration and Pareto optimization of energy retrofit

# Review of dynamic tools



- The most famous software tools for dynamic modeling and performing dynamic simulations:
  - EnergyPlus
  - TRNSYS
  - IDA-Indoor Climate Energy (IDA-ICE)
  - VIP-Energy
  - Modellica
  - ...

# Why EnergyPlus?

- Software for carrying out energy simulations of the entire building for modeling energy consumption - for heating, cooling, ventilation, lighting and preparation of DHW
- The program is based on a console that reads input (data) and writes output (data) to text files
- Advanced exterior opening models including controllable window blinds, electrochromic glazing and layer-by-layer heat balances that calculate solar energy absorbed by window panes
- Component-based HVAC that supports standard and new system configurations
- Extensive and comprehensive documentation



# Why EnergyPlus & DesignBuilder?

- Excellent simulation results between real and modeled heating and cooling loads, 3 % and 5 % respectively \*
- Automation possibilities and use of APIs
- GUI DesignBuilder with easier modelling options and interpretation of results

**MOST IMPORTANT:**

**We have previous experience and know how to use it!**



*EnergyPlus*

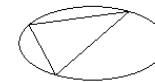
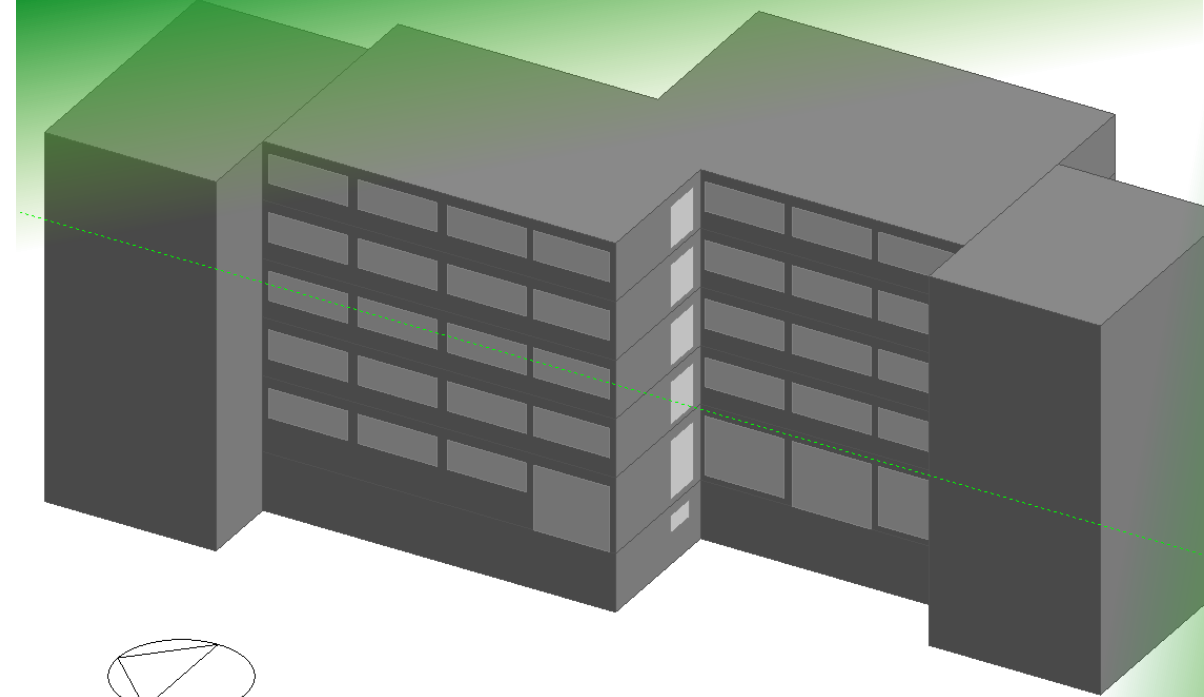


**DesignBuilder**

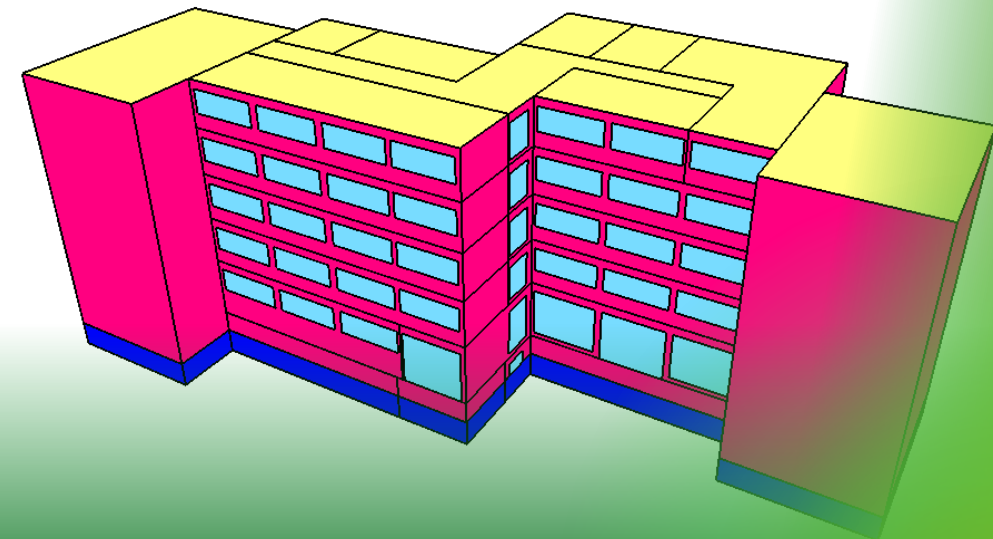
*\*N. Eskin, H. Torkmen, Analysis of annual heating and cooling energy requirements for office buildings in different climates in Turkey, Energy Build. 40 (5) (2008) 763–773*

# Building model

- First step is to model geometry and construction part of existing building model



PU\_podrum eihp  
ZT\_Zid prema tlu  
Hrvatska 2018 K >18°C Glazing



# Building model

- Model all construction materials and elements from existing project documentation, energy audit report or onsite examination

on Template	ion - _VZ_EIHP
<b>ate</b>	<b>Sastav_EIHP</b>
on	ns
l walls	__VZ_EIHP
grade walls	ZT_Zid prema tlu
f	RK_ravni krov
roof (occupied)	Project pitched roof
roof (unoccupied)	Project unoccupied pitched roof
partitions	Project partition
osed	
ni-exposed walls	__VZ_susjed_EIHP
ni-exposed ceiling	Project semi-exposed ceiling
ni-exposed floor	Project semi-exposed floor
und floor	PD_podrum eihp
ormal floor	Project external floor
nal floor	Project internal floor
ces	
ermal Mass	
nt Block	
, Areas and Volumes	
onvection	
ermal Bridging at Junctions	
s	
<b>infiltration</b>	
<b>tion rate at 50 Pa (ac/h)</b>	<b>4.0000</b>
ride wind exposure coefficient	
ride height coefficient	
edule	On 24/7
T and Wind Speed Coefficients	

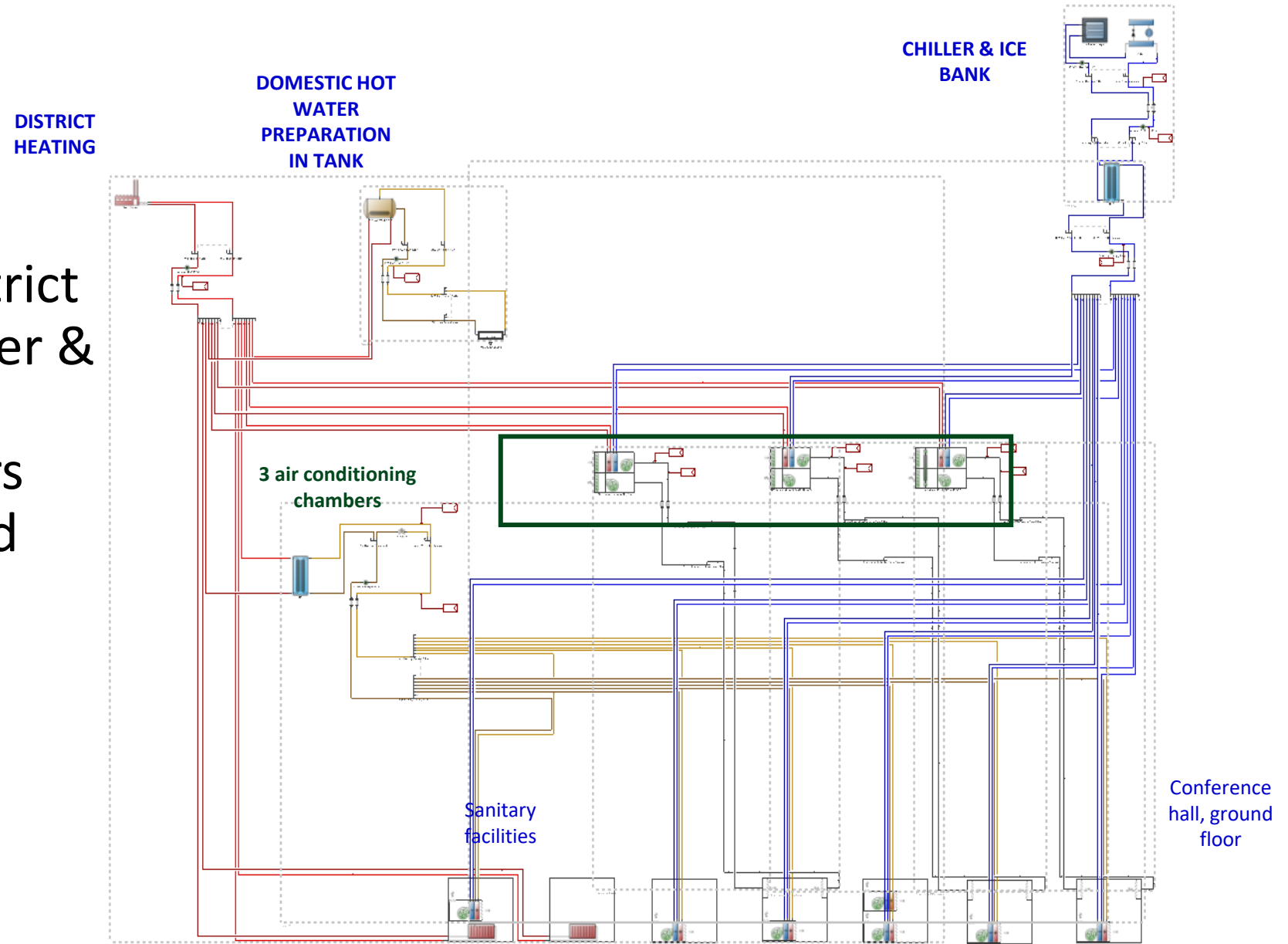
__VZ_EIHP	
Walls	General
method	1-Layers
Settings	
of layers	3
st layer	
erial	Cement/plaster/mo
ess (m)	0,0200
ged?	
erial	Cast Concrete
ess (m)	0,0700
ged?	
st layer	
erial	Min wool quilt, 100
ess (m)	0,1000
ged?	

# HVAC System

- Model existing HVAC system of 250 kW district heating, 76,9 kW chiller & ice bank, 3 air conditioning chambers supplying fan coils and water radiators

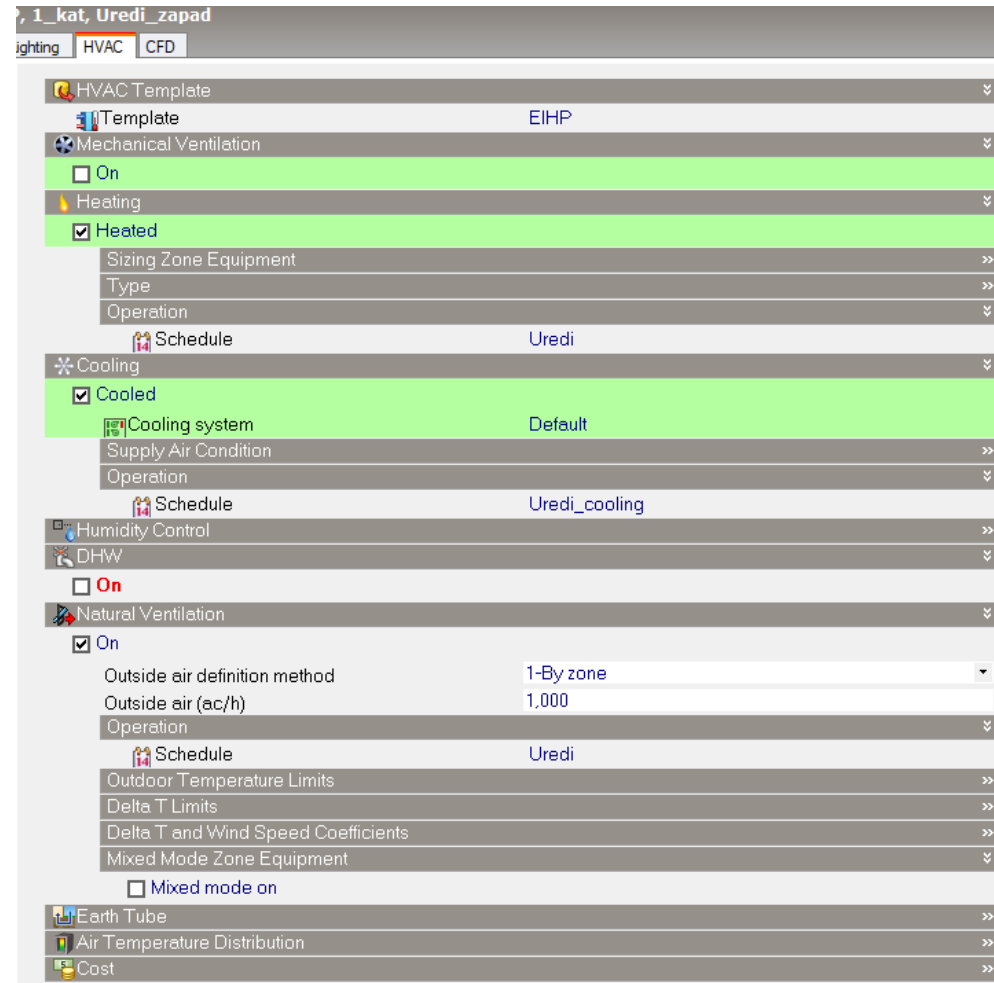


Graphic visualization in DesignBuilder of existing HVAC system at EIHP office building



# HVAC System

- Entry of heating & cooling operation schedules in HVAC tab for each zone



**General**

**Uredi**

Building: OFFICE Area: OPEN PLAN

Source UK NCM

Category Offices / W

Region General

Schedule type 2-Compact

**Profiles**

Schedule: Compact,  
Uredi,  
Temperature,  
Through: 31 Dec,  
For: Weekdays SummerDesignDay  
WinterDesignDay,  
Until: 06:00, 0,  
Until: 22:00, 1,  
Until: 24:00, 0,  
For: Weekends,  
Until: 06:00, 0,  
Until: 16:00, 1,  
Until: 24:00, 0,  
For: Holidays,  
Until: 24:00, 0,  
For: AllOtherDays,  
Until: 24:00, 0;

# Activity tab

- Entry of occupancy schedules, heating and cooling setpoints and electricity consumption of equipment for each zone

Electricity consumption of equipment

The screenshot displays the 'Activity tab' configuration for a zone. The 'Office Equipment' section is highlighted with a green box, showing the following settings:

Section	Parameter	Value
Office Equipment	<input checked="" type="checkbox"/> On	
	Power density (W/m2)	4.90
	Schedule	_EIHP_office_eq
Miscellaneous	<input checked="" type="checkbox"/> On	
	Power density (W/m2)	0.75
	Schedule	_EIHP_miscellaneous

Other visible settings in the 'Activity tab' include:

- Activity Template:** Sector: B1 Offices and Workshop businesses, Zone type: 1-Standard, Zone multiplier: 1, Include zone in thermal calculations: , Include zone in Radiance daylighting calculations:
- Occupancy:** Occupancy density (people/m2): 0,0353, Schedule: \_EIHP\_okupiranost
- Environmental Control:** Heating Setpoint Temperatures: Heating (°C): 24,0, Heating set back (°C): 18,0; Cooling Setpoint Temperatures: Cooling (°C): 24,0, Cooling set back (°C): 27,0

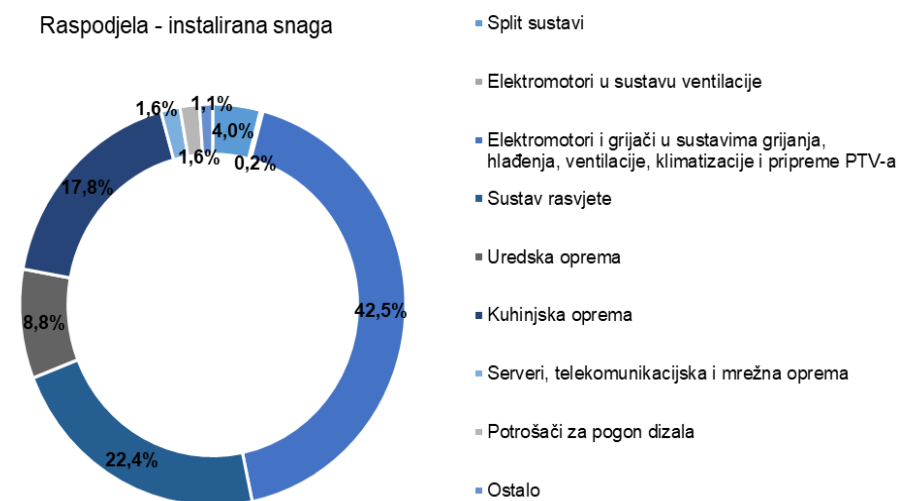
# Electricity consumption model

- Entry and creation of a model for an existing building
  - Getting data from the energy audit, talking with users about how to use the building and the system
- Entry and creation of a model for a new building
  - Getting data from project documentation and use of average usage schedules

# Electricity consumption model

- Systems and groups of electrical consumers:
  - Lighting system
  - Computers
  - Office equipment
  - Kitchen appliances
  - Specific process in building (in case of production)
  - Other equipment

Tip potrošača	Broj	Instalirana snaga [kW]
Uredska oprema	213	19,47
Kuhinjska oprema	16	39,43
Serveri, telekomunikacijska i mrežna oprema	33	3,56
Potrošači za pogon dizala	1	3,60
Ostalo	15	2,44
<b>Ukupno</b>	<b>278</b>	<b>68,50</b>



# Electricity consumption model

- For each system is determined:
  - Installed power of equipment
  - Equipment usage schedule
  - Zoning of equipment
  - Other specific parameters

# Lighting system

EnergyPlus - EnergyPlus Institute Hrvoje Pozar, EIHP, 1\_kat, Uredi\_istok

Layout | **Activity** | Construction | Openings | Lighting | HVAC | CFD

Activity Template

- Template: \_EIHP\_uredi
- Sector: B1 Offices and Workshop businesses
- Zone type: 1-Standard
- Zone multiplier: 1
- Include zone in thermal calculations
- Include zone in Radiance daylighting calculations

Floor Areas and Volumes

Occupancy

Contaminant Generation and Removal

DHW

Environmental Control

Heating Setpoint Temperatures

- Heating (°C): 24,0
- Heating set back (°C): 18,0

Cooling Setpoint Temperatures

- Cooling (°C): 24,0
- Cooling set back (°C): 27,0

Heating Comfort PMV Setpoints

Cooling Comfort PMV Setpoints

Humidity Control

Ventilation Setpoint Temperatures

Minimum Fresh Air

CO2/Contaminant Setpoints

**Lighting**

- Target Illuminance (lux): 500
- Default display lighting density (W/m2): 0

Computers

- On

Office Equipment

Miscellaneous

Catering

Process

Defining of Target Illuminance (lux) in Activity tab

# Lighting system

Entry of lighting system parameters:

Lighting HVAC CFD

Lighting Template

Template EIHP\_rasvjeta\_sve

General Lighting

On

Normalised power density (W/m<sup>2</sup>-100 lux) 3.7830

Schedule \_EIHP\_rasvjeta\_ured

Luminaire type 3-Recessed

Return air fraction 0,000

Radiant fraction 0,370

Visible fraction 0,180

Convective fraction 0,450

Lighting Control

On

Working plane height (m) 0,80

Control type 3-Stepped

Number of steps 3

Glare >>

Lighting Area 1 >>

Lighting Area 2 >>

Task and Display Lighting

On

Cost >>

$$8.301,4 \text{ W} / 438.88 \text{ m}^2 = 18,915 \text{ W/m}^2$$

Illuminance = 500 lux

$$18,915 / 5 = 3,7830 \text{ W/(m}^2 \text{ 100 lux)}$$

the way the lamp is mounted affects the internal gains

Lighting management - stepped 3 steps

# Lighting system

Lighting Template

Template **EIHP\_rasvjeta\_sve**

General Lighting

On

**Normalised power density (W/m2-100 lux)** **3,7830**

Schedule **\_EIHP\_rasvjeta\_ured**

Luminaire type **3-Recessed**

Return air fraction **0,000**

Radiant fraction **0,370**

Visible fraction **0,180**

Convective fraction **0,450**

Lighting Control

On

Working plane height (m) **0,80**

Control type **3-Stepped**

Number of steps **3**

Glare >>

Lighting Area 1 >>

Lighting Area 2 >>

Task and Display Lighting

## Usage Schedule

- Hourly distribution - percentage of lighting which is used

Data Report (Not Editable)

**General**

**\_EIHP\_rasvjeta\_ured**

Source **EIHP**

Category **<General>**

Region **General**

Schedule type **2-Compact**

**Profiles**

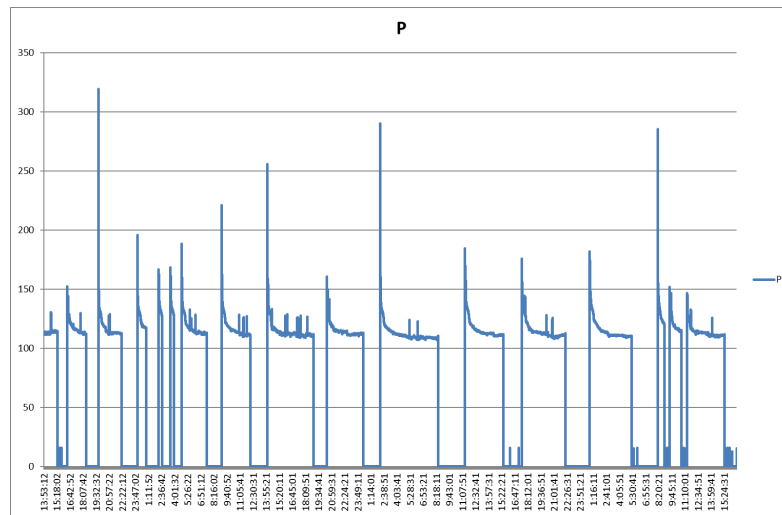
Schedule: Compact,  
\_uredska\_rasvjeta\_ured,  
Fraction,  
Through: 31 Dec,  
For: Weekdays,  
Until: 07:00, 0,  
Until: 09:00, 0,66,  
Until: 11:00, 1,  
Until: 13:00, 0,66,  
Until: 15:00, 1,  
Until: 17:00, 0,66,  
Until: 24:00, 0,  
For: Weekends,  
Until: 24:00, 0,  
For: Holidays,  
Until: 24:00, 0,  
For: AllOtherDays,  
Until: 24:00, 0;

For example between 7 and 9 o'clock, 66 % of installed lighting power is being used

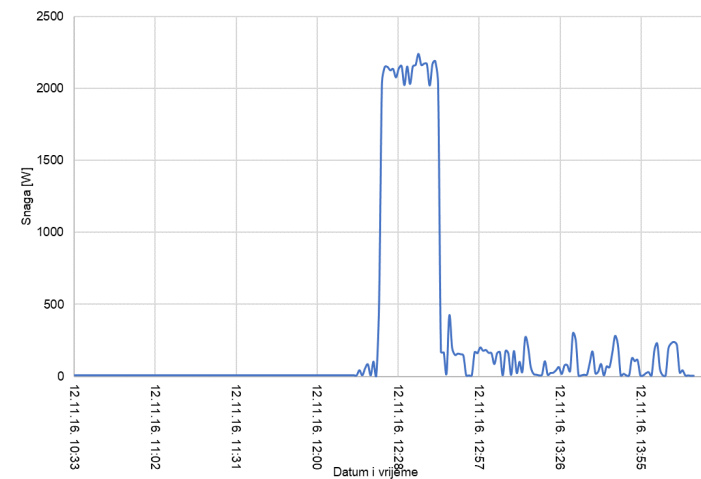
# Equipment

- Depending on individual consumers and usage, different hourly loads

- Example 1– Refrigerator, has relatively the same hourly consumption

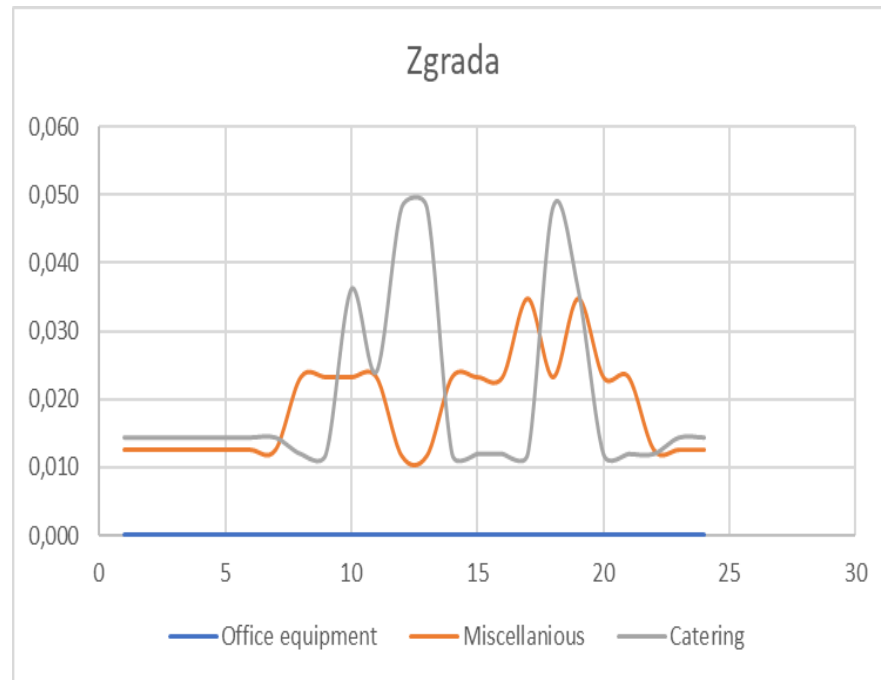


- Example 2– Washing machine, hourly consumption varies significantly



# Equipment

- Elaboration of the model for a typical day at the hourly level of operation of individual devices with a certain probability - marked uncertainty without measurement



- For example, the oven is not turned on every day, and at the same hour - the probability of a coincidence in every day and every hour
- Complex evaluation of the interaction of various devices - the most accurate data 15 min curve of real consumption from the meter

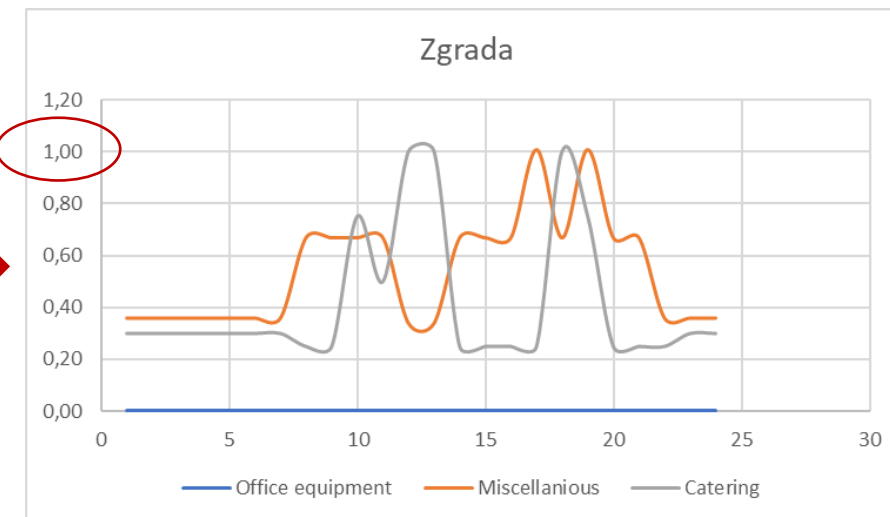
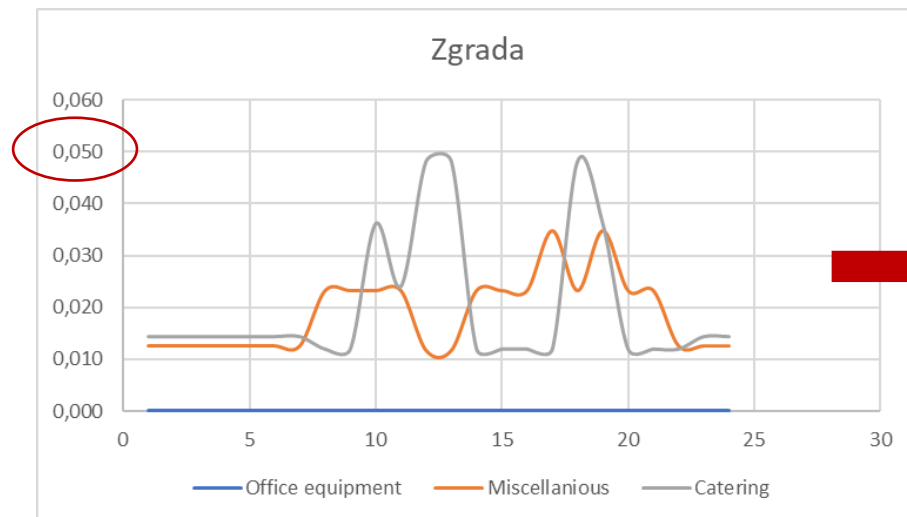
# Equipment

- Entry of normalized power divided with floor area:
  - Normalized power is determined according to the maximum consumption in one hour
  - Be careful with zoning
  - Schedule is determined according to the maximum

60 W/m<sup>2</sup> – real power



60\*0,05= 3 W/m<sup>2</sup> – normalized power



# Equipment

Activity Template

- Template: \_EIHP\_uredi
- Sector: B1 Offices and Workshop businesses
- Zone type: 1-Standard
- Zone multiplier: 1
- Include zone in thermal calculations
- Include zone in Radiance daylighting calculations

Floor Areas and Volumes

- Floor area (m2): 25,04
- Zone volume (m3): 69,61
- Inner surface mode: Deflation

Occupancy

Contaminant Generation and Removal

DHW

Environmental Control

Computers

- On

Office Equipment

- On

Miscellaneous

- On

**Power density (W/m2): 0,75**

Schedule: \_EIHP\_miscellaneous

Fuel: 1 Electricity from grid

Fraction lost: 0,000000

Latent fraction: 0,000000

Radiant fraction: 0,200000

Catering

Process

Data Report (Not Editable)

**General**

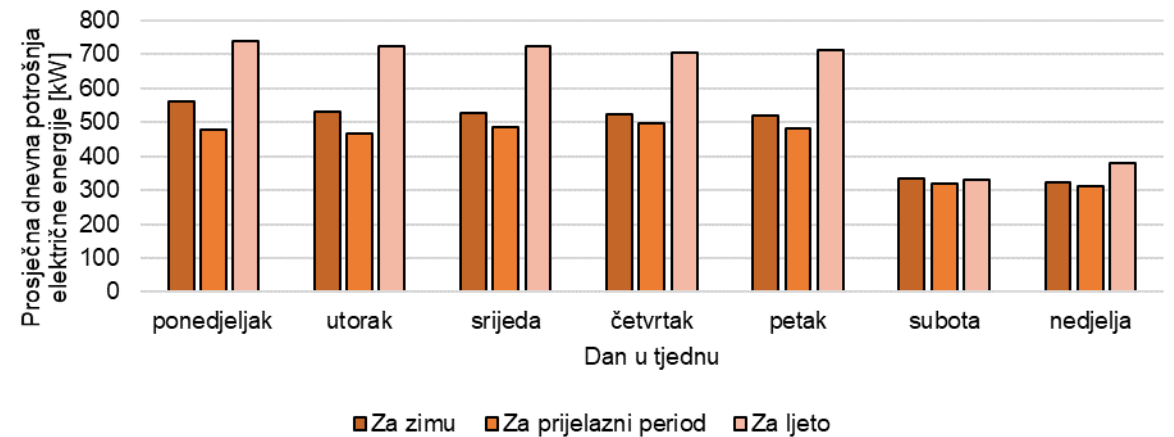
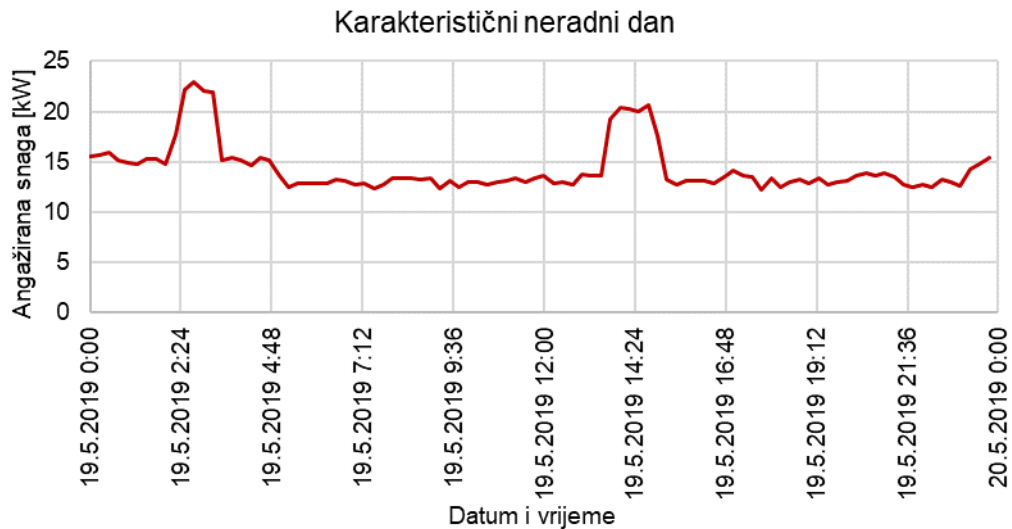
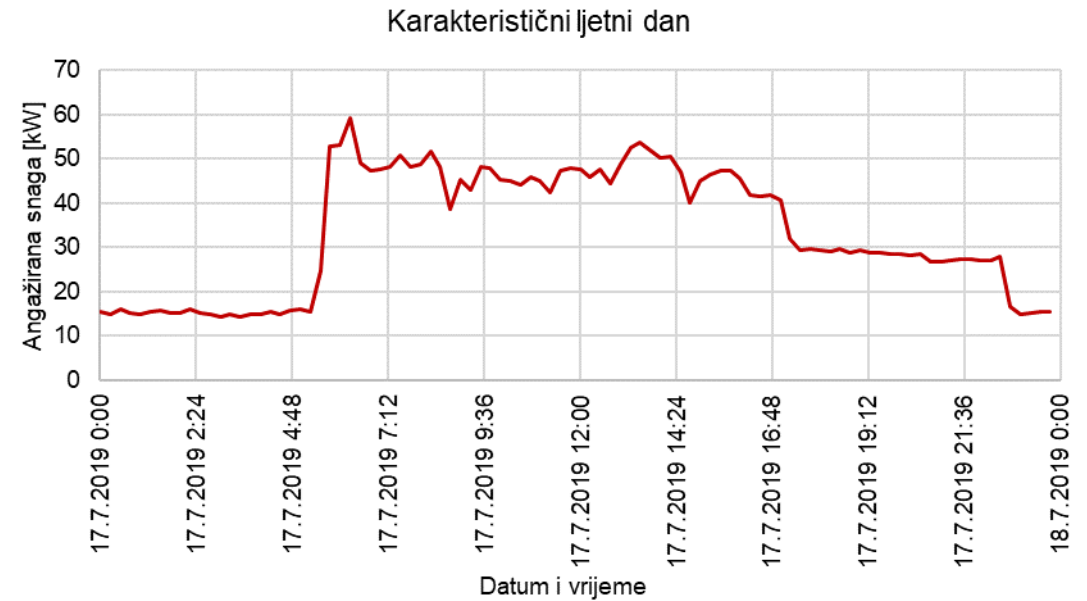
- \_EIHP\_miscellaneous
- Source: EIHP
- Category: <General>
- Region: Hrvatska 2
- Schedule type: 2-Compact

**Profiles**

- Schedule: Compact, \_uredska\_miscellaneous, Fraction, Through: 31 Dec, For: Weekdays, **Until: 07:00, 0.19**, Until: 09:00, 0.5, Until: 16:00, 1, Until: 18:00, 0.5, Until: 24:00, 0.19, For: Weekends, Until: 24:00, 0.19, For: Holidays, Until: 24:00, 0.19, For: AllOtherDays, Until: 24:00, 0.19;

Usage schedule introduces the greatest uncertainty into the calculation - model calibration

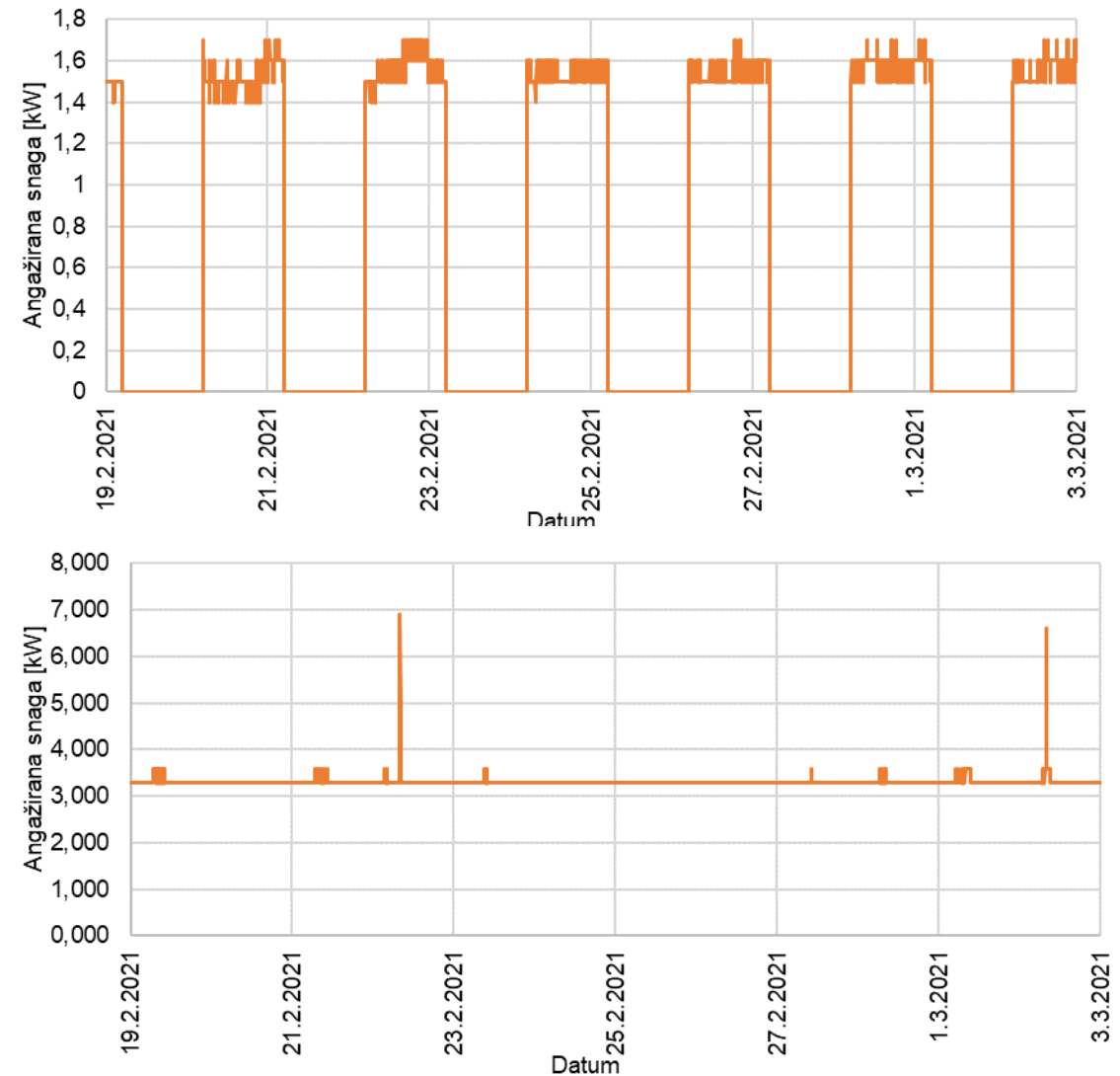
# Measurements



# Measurements

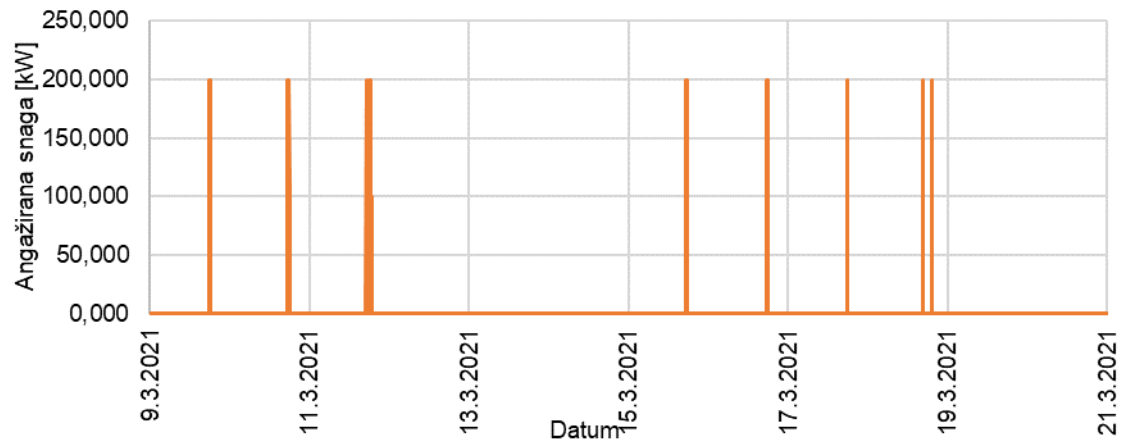
Measurement of electric motor consumption for driving pumps in the heating system

Instalirana snaga mjenog sustava [kW]	7,5
Prosječna izmjerena snaga [kW]	3,3
Radno vrijeme sustava	od 0:00 do 24:00
Pretpostavljeni godišnji broj sati rada [h]	4.368
Godišnja potrošnja električne energije [kWh]	14.480



# Measurements

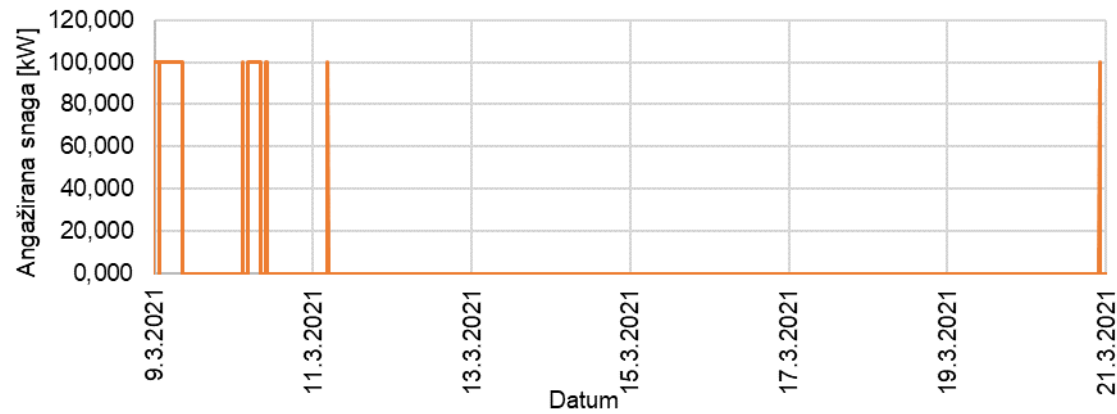
## Measurement of lighting system in hallway



Instalirana snaga mjenog sustava [W]	180
Udio vremena kada se koristila rasvjeta [%]	1,1
Broj sati korištenja u godini [h]	96

# Measurements

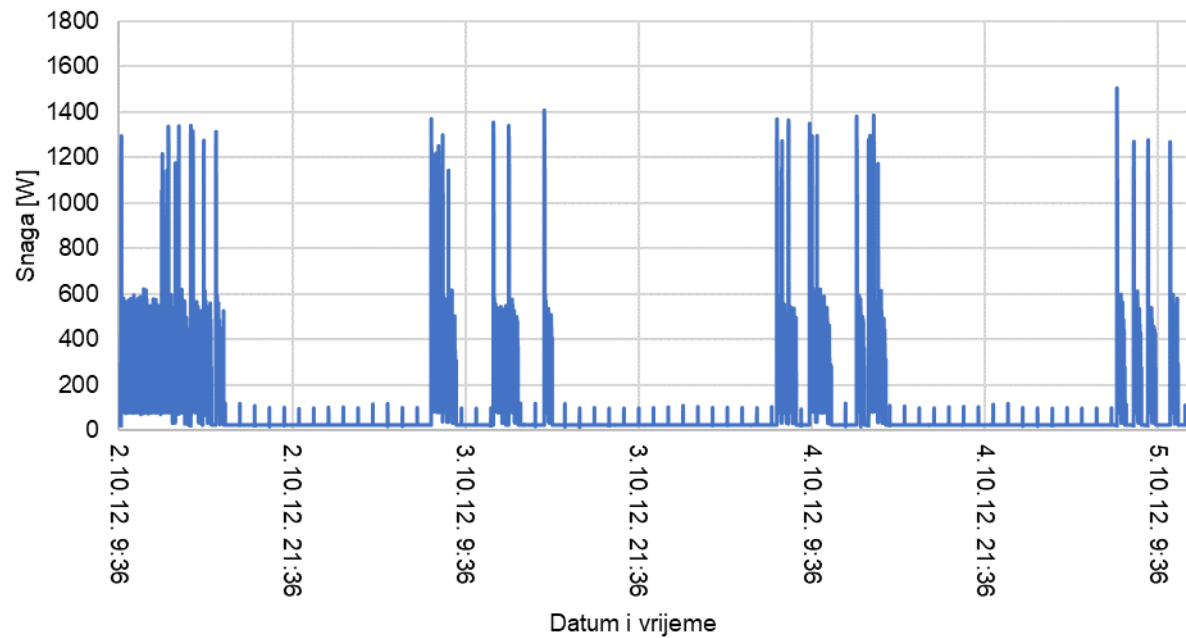
Measurement of electric motor consumption in fan coils



Instalirana snaga mjerenog sustava [W]	174
Udio vremena kada su se koristili ventilokonvektori [%]	15
Broj sati korištenja u godini [h]	1.087

# Measurements

## Measurement on a Minolta Di470 photocopier

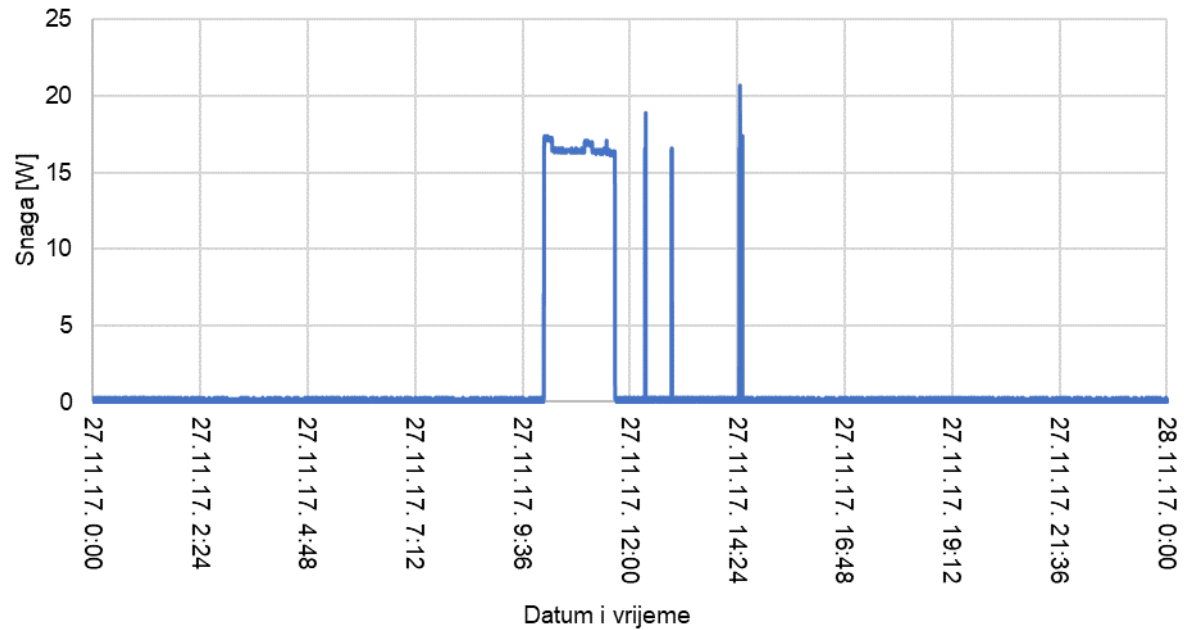


Maksimalna snaga [W]	1.490
Minimalna snaga [W]	14
Nazivna snaga [W]	1.430
Preračunati udio vremena kada se uređaj koristi na nazivnoj snazi [%]	5
Udio rada u višem tarifnom razdoblju [%]	75



# Measurements

## Measurement of the DELL P2414H electronic screen

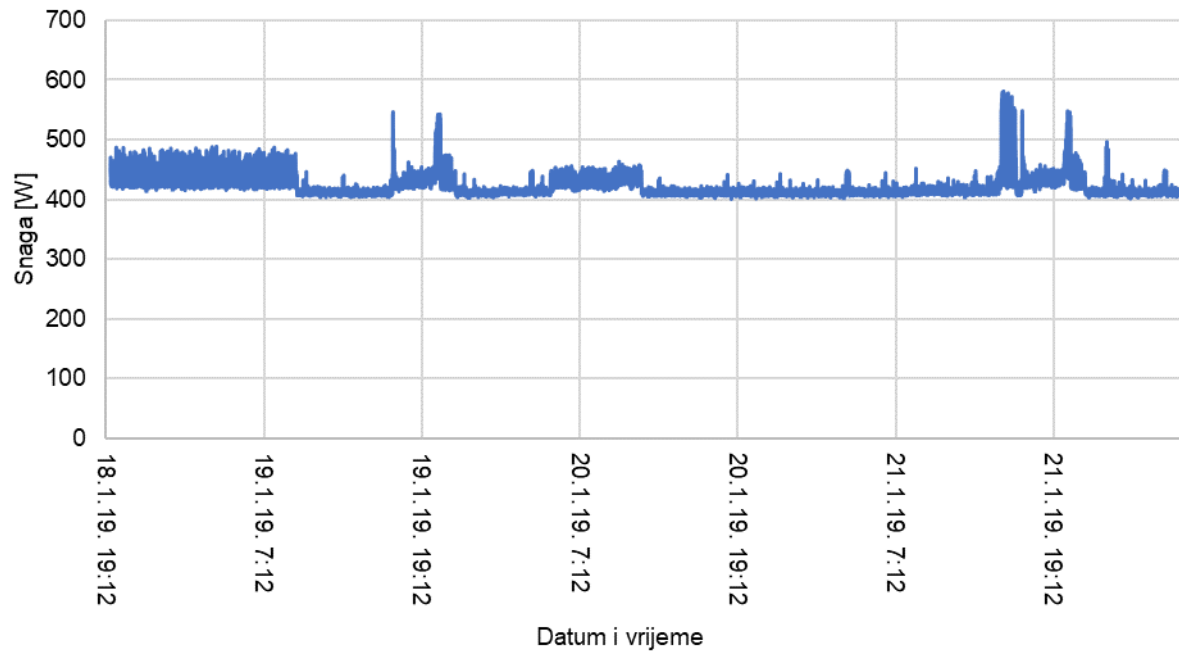


Maksimalna snaga [W]	20,7
Minimalna snaga [W]	0
Nazivna snaga [W]	28
Preračunati udio vremena kada se uređaj koristi na nazivnoj snazi [%]	17
Udio rada u višem tarifnom razdoblju [%]	95



# Measurements

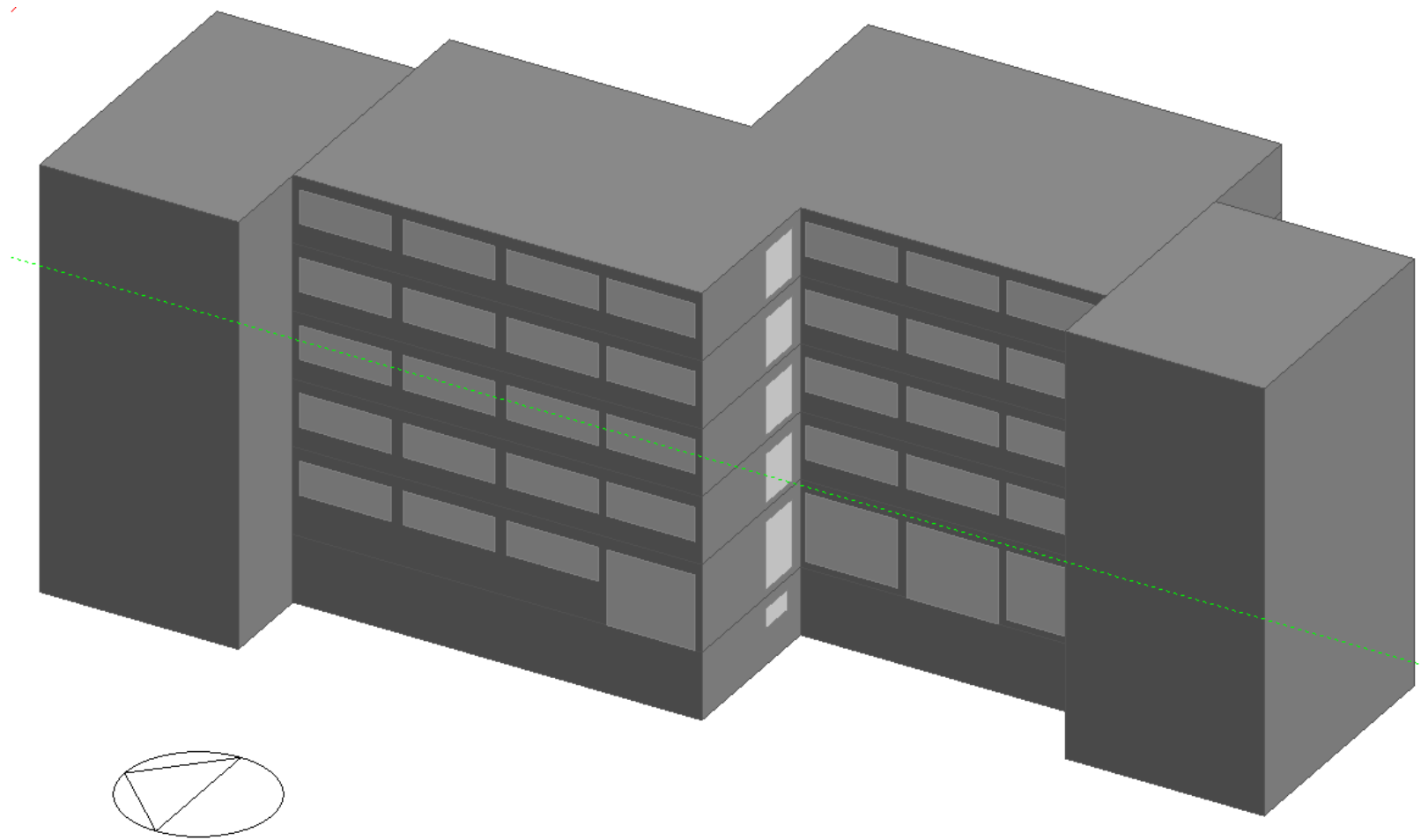
## Measurement of 4 servers on site



Maksimalna snaga [W]	581
Minimalna snaga [W]	401
Nazivna snaga [W]	1.600
Preračunati udio vremena kada se uređaj koristi na nazivnoj snazi [%]	27
Udio rada u višem tarifnom razdoblju [%]	56

# Calibration process

- 3 possible ways of calibrating model dependent on data availability:
  - Annual model
  - Monthly model
  - Hourly & subhourly model

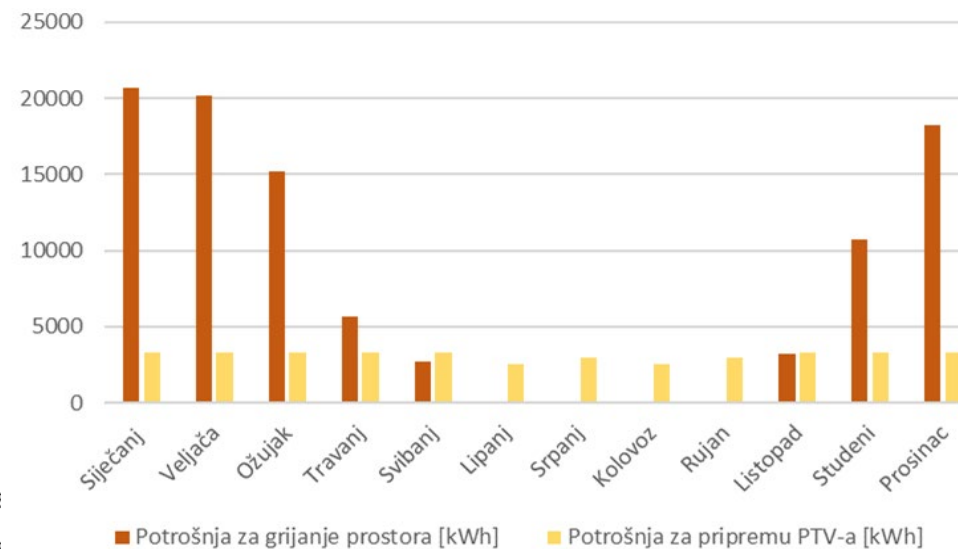


# Energy bills

Reference values related to annual heating energy and cost



Distribution of heating energy and energy for preparation of DHW



Annual consumption and cost of water

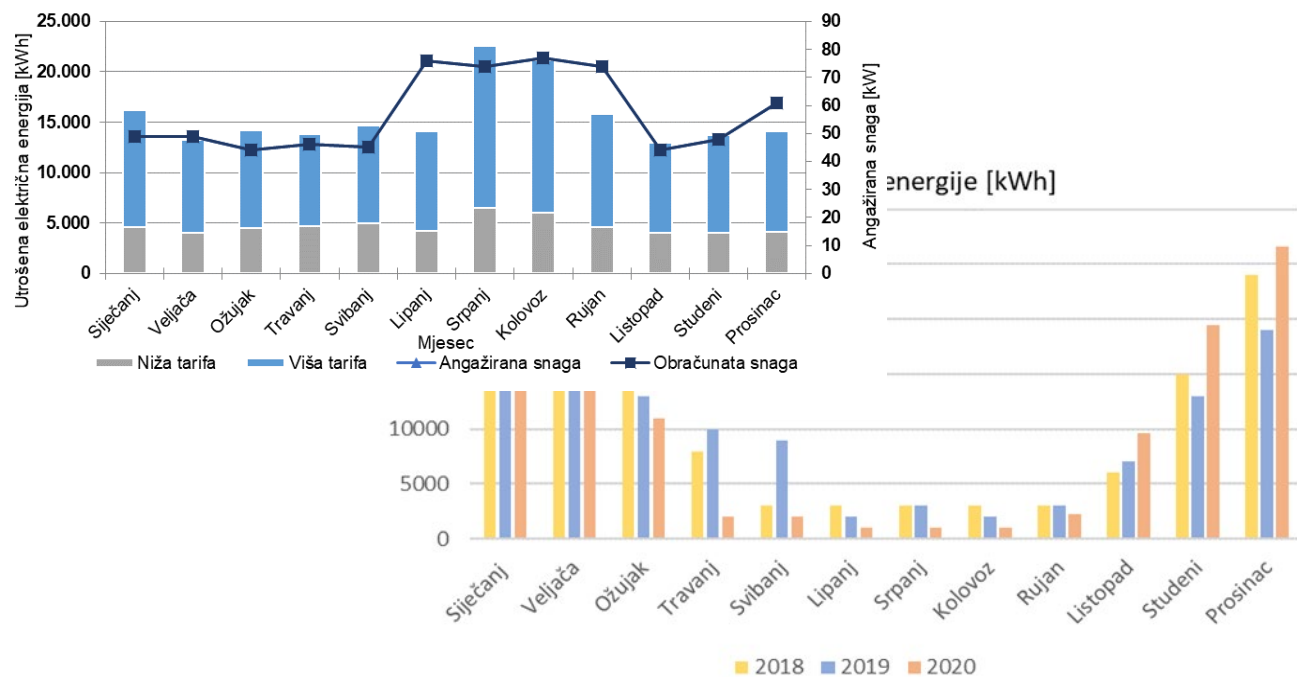
m3  
kn

# Energy bills and energy audit

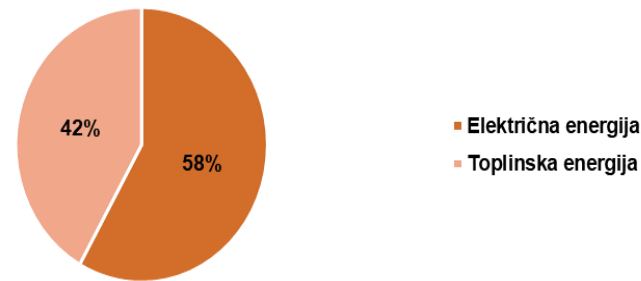
Reference values related to energy and water consumption for the building (2019)

Energenti i voda	Jedinica	Referentne vrijednosti		
		Godišnja potrošnja	Godišnja potrošnja energije	Godišnja emisija CO <sub>2</sub>
		[jedinica/god.]	[kWh/god.]	[tona/god.]
Električna energija	kWh	186.539,00	186.539,00	43,837
Toplinska energija	kWh	134.000,00	134.000,00	46,364
Voda	m <sup>3</sup>	1.051,50	-	0,236
<b>Ukupno</b>			<b>320.539,00</b>	<b>90,437</b>

Total reference consumption of electricity in higher and lower tariffs and engaged power by month from January to December

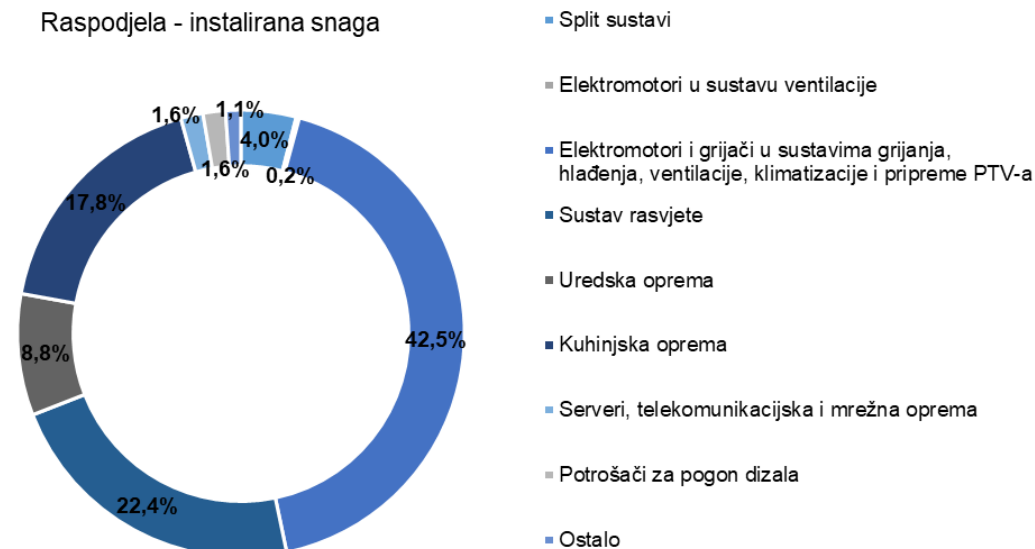


Shares of individual forms in reference energy consumption



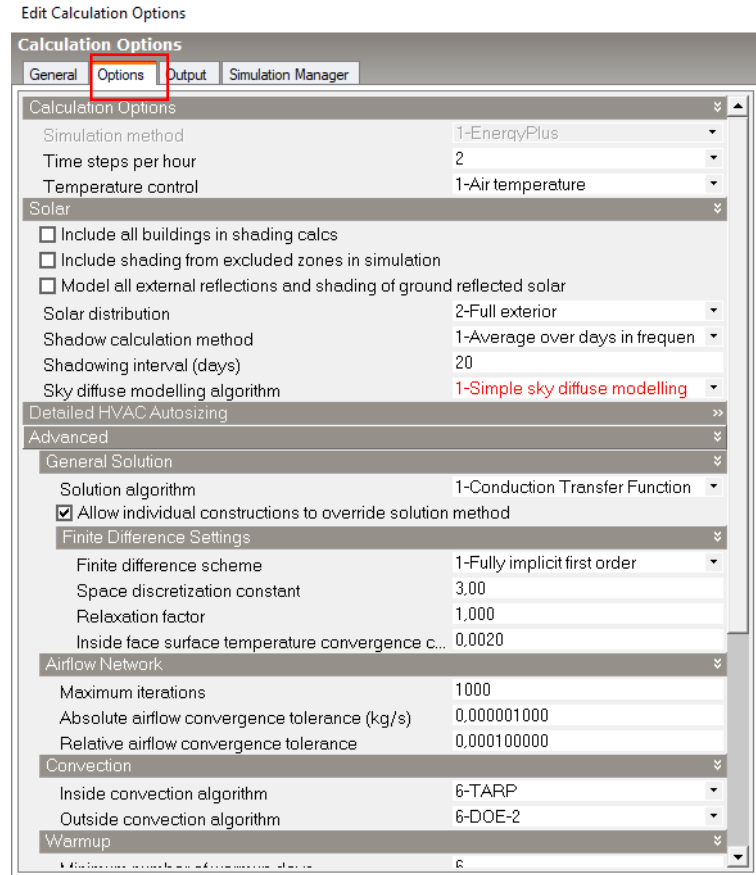
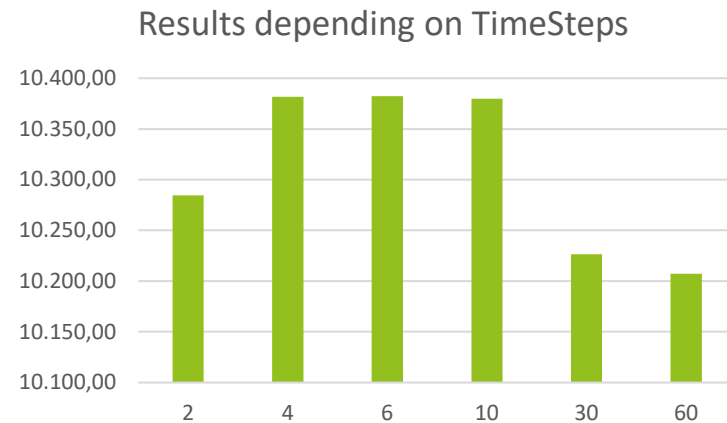
Distribution of main groups of consumers according to installed power

Raspodjela - instalirana snaga



# Time Step Factor

Time steps per hour	Run simulation Time	Total Energy [kWh]	10284,5
2	0:00:24	10.284,53	-0,000292%
4	0:00:34	10.381,63	-0,944431%
6	0:00:46	10.382,20	-0,949973%
10	0:01:08	10.379,82	-0,926832%
30	0:02:44	10.226,57	0,563275%
60	0:04:37	10.207,12	0,752394%



# Final Calibration Results

## Site and Source Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	288684.49	120.62	137.46
Net Site Energy	288684.49	120.62	137.46

## End Uses

	Electricity [kWh]	Natural Gas [kWh]	Additional Fuel [kWh]	District Cooling [kWh]	District Heating [kWh]	Water [m3]
Heating	0.00	0.00	0.00	0.00	130235.82	0.00
Cooling	31478.37	0.00	0.00	0.00	0.00	0.00
Interior Lighting	38702.65	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	53401.74	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	17217.96	0.00	0.00	0.00	0.00	0.00
Pumps	17638.81	0.00	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	365.77
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
<b>Total End Uses</b>	<b>158448.68</b>	0.00	0.00	0.00	<b>130235.82</b>	365.77

Energenti i voda	Jedinica	Referentne vrijednosti		
		Godišnja potrošnja	Godišnja potrošnja energije	Godišnja emisija CO <sub>2</sub>
		[jedinica/god.]	[kWh/god.]	[tona/god.]
Električna energija	kWh	186.539,00	186.539,00	43,837
Toplinska energija	kWh	134.000,00	134.000,00	46,364
Voda	m <sup>3</sup>	1.051,50	-	0,236
<b>Ukupno</b>			<b>320.539,00</b>	<b>90,437</b>

# EMS & FMU Scripts

DesignBuilder - EIHP\_kalibrirani model\_CTS\_ref.dsb - Lighting - Energetski institut Hrvoje Pozar, EIHP, 4\_kat, Server\_soba

File Go Tools Help

Script Manager

Scripts

General

Enable scripts

Script Building Average Zone Air Temp

Enable FMU

Help

Info Data

Script

EMS

Banka leda

- Building Average Zone Air Temperature
- Change Heating and Cooling Setpoints Daily
- CIBSE TM52 Reports
- CIBSE TM59 Reports
- CIBSE TM59 Ventilation temperature control enhancement
- CO2 control (On/Off)
- CO2 control (Proportional)
- Copy of Building Average Zone Air Temperature
- DHW\_Water Heater
- DIN 4108-2 2013-02 DEFAULT INT BLIND - AUTOMATIC
- DIN 4108-2 2013-02 DEFAULT INT BLIND - MANUAL

Data Report (Not Editable)

General

**Building Average Zone Air Temperature**

Calculate building average zone temperature for the occupied zones

Category EMS

Script

**Enable program No**

I report average air temperature of all occupied zones in building

I for all occupied zones create sensors and internal variables for temperature and zone air volume respectively

<ForAllOccupiedZones>

EnergyManagementSystem:Sensor,  
Temp\_<LoopZoneVariableName>,  
<LoopZoneIDFName> ,  
Zone Mean Air Temperature ;

EnergyManagementSystem:InternalVariable,  
Vol\_<LoopZoneVariableName>,  
<LoopZoneIDFName>

Help Cancel OK

```

General
Name Change Heating and Cooling Setpoints Daily
Description Change the setpoints based on the day of the week.
Category EMS
Script
 Enable program
Schedule_Value_<LoopZoneVariableName>_COOLING_SP_SCH,
<LoopZoneIDFName> COOLING SP SCH,
Schedule:Compact,
Schedule Value;

EnergyManagementSystem:Actuator,
Schedule_Value_<LoopZoneVariableName>_HEATING_SETPOINT_SCHEDULE,
<LoopZoneIDFName> HEATING SETPOINT SCHEDULE,
Schedule:Compact,
Schedule Value;
<LoopNextZone>

EnergyManagementSystem:ProgramCallingManager,
My_Setpoint_Schedule_Calculator_Example,
BeginTimestepBeforePredictor,
MyComputedCoolingSetpointProg,
MyComputedHeatingSetpointProg;

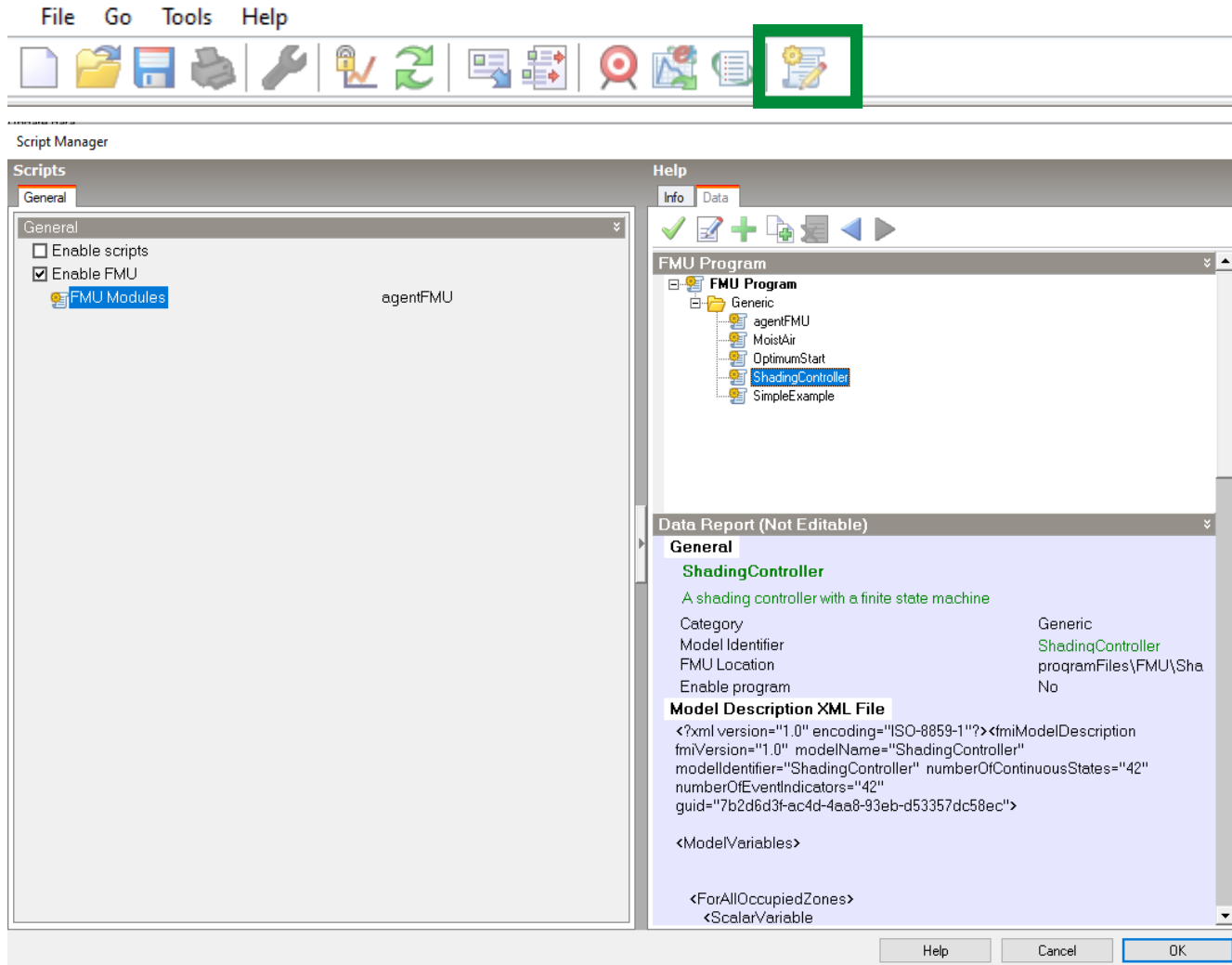
EnergyManagementSystem:Program,
MyComputedCoolingSetpointProg,
IF DayOfWeek < 6 && Holiday == 0,
<ForAllOccupiedZones>
Set Schedule_Value_<LoopZoneVariableName>_COOLING_SP_SCH = 26.0,
<LoopNextZone>
Else,
<ForAllOccupiedZones>
Set Schedule_Value_<LoopZoneVariableName>_COOLING_SP_SCH = 100.0,
<LoopNextZone>
Endif;

EnergyManagementSystem:Program,
MyComputedHeatingSetpointProg,
IF DayOfWeek < 6 && Holiday == 0,
<ForAllOccupiedZones>
Set Schedule_Value_<LoopZoneVariableName>_HEATING_SETPOINT_SCHEDULE = 21.0,
<LoopNextZone>
Else,
<ForAllOccupiedZones>
Set Schedule_Value_<LoopZoneVariableName>_HEATING_SETPOINT_SCHEDULE = 15.0,
...

```

# EMS & FMU Scripts

DesignBuilder - EIHP\_kalibrirani model\_CTS\_ref.dsb - Lighting - Energetski institut Hrvoje Pozar, EIHP, 4\_kat, Server\_soba



- FMU – Functional Mock-up Unit - representation of a dynamic system based on a tool independent standard interface called Functional Mockup Interface (FMI)
- enables the exchange of models from a very diverse range of **domains** and **applications**
- used to perform co-simulation and real time simulations by coupling systems
- Example: EnergyPlus & Modelica + real measured data

**If you would like more information,  
please visit [www.timepac.eu](http://www.timepac.eu) or contact us at  
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Thanks for your attention!