PROJECT ASSIGNMENT: Modelling and simulation of a 4-unit apartment building

INTRODUCTION

This project assignment aims to use a BPS tool (i.e., OpenStudio) to build the energy model of a two-storey building and estimate its energy performance.

The case study is an apartment building (for the location see Table 1). It consists of four residential units (i.e., four apartments) arranged on two floors, with a total gross volume of approximately 3,200 m^3 and a total heated net floor area of roughly 500 m^2 (see plans for more details).

The class will be divided into groups of (tentatively) **4 students**. However, the project assignment will require both individual and group work.

Table 1 – Project details

Group	Location	Climatic Zone	Orientation	Design category
1 & 2	Oslo	Search for your location in the "Climatic Data.pdf" file and use the respective climatic zone.	North 25°	Category II
3 & 4	Athens		North 35°	Category II
5 & 6	Rome		North 45°	Category II
7 & 8	Paris		North -45°	Category II
9 & 10	Madrid		North -35°	Category II
11 & 12	Berlin		North -25°	Category II

DESCRIPTION OF THE TASKS

The idea is that first, the students work individually. Each student will model one of the four apartments. Next, all members of one group join together and peer-review their models to fix errors and share the solutions adopted during the modelling step. Then, they work together to develop a shared building model for the entire 4-unit apartment building.

In the **first phase**, each group member shall work individually on the tasks below:

1. Create a building energy model (BEM) of the entire 4-unit apartment building by setting the given location and the weather file, creating the building geometry and applying the appropriate envelope components, defining the thermal zoning, choosing the simulation set-up, and modelling properly the involuntary infiltration and the opening of windows and doors. At this stage, the heating system can be considered ideal, and the setpoint values of the heating and cooling system are described in Table 1. The focus should be on energy needs for space heating and cooling, peak power for space heating and cooling, and thermal comfort during winter and summer. While the model is defined for the entire building, at this stage, each student should perform the energy simulation for only one apartment (each student must model a different apartment).
2. Simulate the model and estimate the apartment's energy performance using the given input.
3. Finally, propose and discuss at least two strategies to simultaneously increase energy efficiency and indoor environmental quality.

In the **second phase**, the group will work together on the tasks below:

1. Build the model for the entire 4-unit apartment building and integrate the solution adopted by the single group member, if meaningful.
2. Consider a realistic heating and cooling system and relative schedule setpoint. Additionally, optimise the model for the entire building (e.g., improve control strategies for solar shading, night cooling ventilation, window opening, etc.).
3. Propose a change in the design of the building to improve its performance. However, the building should still have the following characteristics:
    a. The number of apartments should be the same.
    b. The floor area of each apartment should remain roughly the same.
4. Additionally, assess the performance of the old and updated design.

First phase, overall objectives
Descriptions of the modelling steps + simulation results + overheating

Due **9 am** October 31.

Each student shall write a maximum seven-page report describing the implementation in OpenStudio (i.e., input data + definition of the model) and summarising the main outcomes. Specifically, the student shall:

1. Describe model implementation and key parameters: (1 page with visuals)
   – Location, apartment and thermal zoning
   – Ventilation and internal gains
2. Build one model with ideal systems for space heating and cooling and report the following outputs: (0.5 page)
   – Annual energy need for space heating (kWh/(m^2 y))
   – Annual energy need for space cooling (kWh/(m^2 y))
   – Peak power for space heating (kW)
   – Peak power for space cooling (kW)
3. Delete the ideal systems and run the model in free-running mode throughout the year. Then, report: (0.5 page)
   – Free-running zones maximum temperature (ºC)
   – Free-running zones minimum temperature (ºC)
4. Compare and discuss the results of at least two implemented strategies used to simultaneously increase energy efficiency and indoor environmental quality. Evaluate the efficacy of the strategies referencing the base model (i.e., model without strategies). (up to 5 pages with visuals)

To communicate and describe the results, choose appropriate tools (e.g., tables, visuals).

Second phase, overall objectives
Description of the implementation of what has been learned from individual work (shading, zoning, schedule, overheating), modelling of the heating and cooling system + model optimisation + final thermal comfort and air quality (e.g., CO2) evaluation.

The group shall describe briefly the implementation in OpenStudio (i.e., input data + definition of the model) and summarise the main outcomes. Specifically, the group shall:

1. Build the model for the entire 4-unit apartment building and integrate the solution the single group member adopted, if meaningful.
2. Implement a realistic system for space heating and cooling and report the following outputs:
   – Annual energy need for space heating (kWh/(m^2 y))
   – Annual energy need for space cooling (kWh/(m^2 y))
   – Peak power for space heating (kW)
   – Peak power for space cooling (kW)
3. Propose a change in the design of the building to improve its performance. However, the building should still have the following characteristics:
   c. The number of apartments should be the same.
   d. The floor area of each apartment should remain roughly the same.
4. Assess and discuss the performance of the old and updated design.

PROJECT DETAILS

Table 2 – Number of people

Apartment	People	Floor area	People per floor area
Apartment 1	4	~ 128 m^2	~ 0.031
Apartment 2	3	~ 128 m^2	~ 0.023
Apartment 3	2	~ 128 m^2	~ 0.016
Apartment 4	2	~ 128 m^2	~ 0.016

Table 3 – Default categories for design of mechanical heated and cooled buildings

Category	Thermal state of the body as a whole	
	Predicted percentage of dissatisfied PPD	Predicted mean vote PMV
I	< 6%	-0.2 < PMV < +0.2
II	< 10%	-0.5 < PMV < +0.5
III	< 15%	-0.7 < PMV < +0.7
IV	< 25%	-1.0 < PMV < +1.0

Table 4 – Default design values of the indoor operative temperature

Type of building/space	Category	Operative temperature		Relative humidity	
		Minimum for heating	Maximum for cooling	Dehumidification	Humidification
Residential	I	21.0°C	25.5°C	55%	45%
	II	20.0°C	26.0°C	65%	40%
	III	18.0°C	27.0°C	70%	30%
	IV	16.0°C	28.0°C	70%	30%

Table 5 – Metabolic Rates for Various Activities

Activity	Activity Level EnergyPlus Schedule	Activity Level	Met*
Resting			
Sleeping	72 W/person	40 W/m^2	0.7
Reclining	81 W/person	45 W/m^2	0.8
Seated, quiet	108 W/person	60 W/m^2	1
Standing, relaxed	126 W/person	70 W/m^2	1.2
Walking 3.2 km/h	207 W/person	115 W/m^2	2
Walking 4.3 km/h	270 W/person	150 W/m^2	2.6
Walking 6.4 km/h	396 W/person	220 W/m^2	3.8
*1 met = 58.1 W/m^2			

Table 6 – Ventilation rates

Category	Airflow per person
I	10 l/(s·person)
II	7 l/(s·person)
III	4 l/(s·person)
IV	2.5 l/(s·person)

For infiltration assume a constant air changes per hour of 0.6 1/h

Table 7 – Suggested load

Room	Artificial lighting	Electric equipment
Bathroom	6 W/m^2	2 W/m^2
Bedroom	6 W/m^2	5 W/m^2
Kitchen	6 W/m^2	40 W/m^2
Living room	6 W/m^2	5 W/m^2
Studio	6 W/m^2	10 W/m^2

Table 8 – Suggested schedule for living room

Occupancy	Artificial lighting	Electric equipment
• For: weekdays	• For: weekdays	• For: weekdays
— Until: 07:00, 0	— Until: 07:00, 0	— Until: 07:00, 0.05
— Until: 09:00, 0.5	— Until: 09:00, 1	— Until: 09:00, 1
— Until: 18:00, 0	— Until: 18:00, 0	— Until: 18:00, 0.05
— Until: 20:00, 0.5	— Until: 20:00, 1	— Until: 20:00, 1
— Until: 24:00, 0	— Until: 24:00, 0	— Until: 24:00, 0.05
• For: weekends	• For: weekends	• For: weekends
— Until: 09:00, 0	— Until: 09:00, 0	— Until: 09:00, 0.05
— Until: 11:00, 0.5	— Until: 11:00, 1	— Until: 11:00, 1
— Until: 13:00, 0	— Until: 13:00, 0	— Until: 13:00, 0.05
— Until: 14:00, 0.5	— Until: 14:00, 1	— Until: 14:00, 1
— Until: 18:00, 0	— Until: 18:00, 0	— Until: 18:00, 0.05
— Until: 21:00, 0.5	— Until: 21:00, 1	— Until: 21:00, 1
— Until: 24:00, 0	— Until: 24:00, 0	— Until: 24:00, 0.05
• For: Holidays	• For: Holidays	• For: Holidays
— Until: 24:00, 0	— Until: 24:00, 0	— Until: 24:00, 0.05

Table 9 – Suggested schedule for kitchen

Occupancy	Artificial lighting	Electric equipment
• For: weekdays	• For: weekdays	• For: weekdays
— Until: 07:00, 0	— Until: 07:00, 0	— Until: 07:00, 0.05
— Until: 09:00, 0.5	— Until: 09:00, 1	— Until: 09:00, 1
— Until: 17:00, 0	— Until: 17:00, 0	— Until: 17:00, 0.05
— Until: 19:00, 0.5	— Until: 19:00, 1	— Until: 19:00, 1
— Until: 24:00, 0	— Until: 24:00, 0	— Until: 24:00, 0.05
• For: weekends	• For: weekends	• For: weekends
— Until: 09:00, 0	— Until: 09:00, 0	— Until: 09:00, 0.05
— Until: 11:00, 0.5	— Until: 11:00, 1	— Until: 11:00, 1
— Until: 13:00, 0	— Until: 13:00, 0	— Until: 13:00, 0.05
— Until: 14:00, 0.5	— Until: 14:00, 1	— Until: 14:00, 1
— Until: 17:00, 0	— Until: 17:00, 0	— Until: 17:00, 0.05
— Until: 20:00, 0.5	— Until: 20:00, 1	— Until: 20:00, 1
— Until: 24:00, 0	— Until: 24:00, 0	— Until: 24:00, 0.05
• For: Holidays	• For: Holidays	• For: Holidays
— Until: 24:00, 0	— Until: 24:00, 0	— Until: 24:00, 0.05

Table 10 – Suggested schedule for bedroom

Occupancy	Artificial lighting	Electric equipment
• For: weekdays	• For: weekdays	• For: weekdays
— Until: 07:00, 1	— Until: 07:00, 0	— Until: 07:00, 0.05
— Until: 09:00, 0.5	— Until: 09:00, 1	— Until: 09:00, 1
— Until: 21:00, 0	— Until: 18:00, 0	— Until: 18:00, 0.05
— Until: 22:00, 0.25	— Until: 23:00, 1	— Until: 23:00, 1
— Until: 23:00, 0.5	— Until: 24:00, 0	— Until: 24:00, 0.05

— Until: 24:00, 1		
• For: weekends	• For: weekends	• For: weekends
— Until: 08:00, 1	— Until: 07:00, 0	— Until: 07:00, 0.05
— Until: 09:00, 0.5	— Until: 09:00, 1	— Until: 09:00, 1
— Until: 11:00, 0.25	— Until: 18:00, 0	— Until: 18:00, 0.05
— Until: 21:00, 0	— Until: 23:00, 1	— Until: 23:00, 1
— Until: 22:00, 0.25	— Until: 24:00, 0	— Until: 24:00, 0.05
— Until: 23:00, 0.5		
— Until: 24:00, 1		
• For: Holidays	• For: Holidays	• For: Holidays
— Until: 24:00, 0	— Until: 24:00, 0	— Until: 24:00, 0.05

Table 11 – Suggested schedule for studio

Occupancy	Artificial lighting	Electric equipment
• For: weekdays	• For: weekdays	• For: weekdays
— Until: 07:00, 0	— Until: 18:00, 0	— Until: 18:00, 0.05
— Until: 09:00, 0.5	— Until: 21:00, 1	— Until: 21:00, 1
— Until: 18:00, 0	— Until: 24:00, 0	— Until: 24:00, 0.05
— Until: 21:00, 0.25		
— Until: 24:00, 0		
• For: weekends	• For: weekends	• For: weekends
— Until: 07:00, 0	— Until: 16:00, 0	— Until: 16:00, 0.05
— Until: 09:00, 0.5	— Until: 20:00, 1	— Until: 20:00, 1
— Until: 16:00, 0	— Until: 24:00, 0	— Until: 24:00, 0.05
— Until: 20:00, 0.25		
— Until: 24:00, 0		
• For: Holidays	• For: Holidays	• For: Holidays
— Until: 24:00, 0	— Until: 24:00, 0	— Until: 24:00, 0.05

Table 12 – Suggested schedule for bathroom

Occupancy	Artificial lighting	Electric equipment
• For: weekdays	• For: weekdays	• For: weekdays
— Until: 07:00, 0	— Until: 07:00, 0	— Until: 07:00, 0.05
— Until: 09:00, 0.5	— Until: 09:00, 1	— Until: 09:00, 1
— Until: 19:00, 0	— Until: 19:00, 0	— Until: 19:00, 0.05
— Until: 22:00, 0.1	— Until: 22:00, 1	— Until: 22:00, 1
— Until: 24:00, 0	— Until: 24:00, 0	— Until: 24:00, 0.05
• For: weekends	• For: weekends	• For: weekends
— Until: 09:00, 0	— Until: 09:00, 0	— Until: 09:00, 0.05
— Until: 11:00, 0.5	— Until: 11:00, 1	— Until: 11:00, 1
— Until: 19:00, 0	— Until: 19:00, 0	— Until: 19:00, 0.05
— Until: 21:00, 0.1	— Until: 21:00, 1	— Until: 21:00, 1
— Until: 24:00, 0	— Until: 24:00, 0	— Until: 24:00, 0.05
• For: Holidays	• For: Holidays	• For: Holidays
— Until: 24:00, 0	— Until: 24:00, 0	— Until: 24:00, 0.05

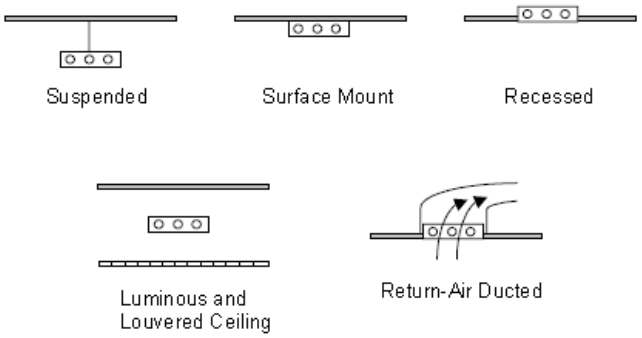

Fig. 1 – Luminaire type

Table 13 – Luminaire type (assuming fluorescent lighting)

Data	Suspended	Surface Mount	Recessed	Luminous and Recessed Ceiling	Return-air Ducted
Return Air Fraction	0.00	0.00	0.00	0.00	0.54
Radiant Fraction	0.42	0.72	0.37	0.37	0.18
Visible Fraction	0.18	0.18	0.18	0.18	0.18
Convected Fraction	0.40	0.10	0.45	0.45	0.10