Building simulation assignment

11127 Sustainable heating and cooling of buildings

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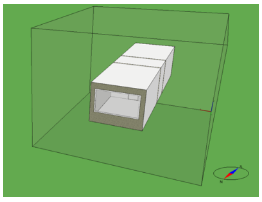


Introduction

To achieve a satisfactory indoor environment, two primary factors are to be considered : indoor air quality and indoor temperatures. These can be regulated through ventilation and heating & cooling devices, which are selected according to the users needs, the building location and the weather data.

The purpose of this assignment was to produce a realistic model of an office building, represented by two office zones orientated North and South, separated by a corridor. Two heating alternatives were considered, either floor heating or water radiators, and additional cooling solutions were then implemented depending on the case, either passive (solar shadings, natural venting) or mechanical. The buildings are to be set in three different locations : Copenhagen, Oslo and Rome. Simulations are then run to determine the main parameters: influencing indoor climate and energy consumption of the building. The occupants comfort and energy consumption will then be compared with the building regulations (BR2010, BR2015, BR2020).

Methodology

The simulation models are built upon the pre-prepared model file given in the course. Location is then set using an IDA ICE weather file. Copenhagen and Rome simulation use TRY files while Oslo uses an IWEC file. The building is considered occupied from 8 am to 5 pm on weekdays, and empty otherwise. Light and equipment function on the same schedule.

The model is then updated by removing the ideal heater and cooler devices, and replaced by one of two alternatives : either a window water radiator, or a floor heating/cooling device. At first a heating load simulation is run using only the heating device. Afterwards, the design is optimized to comply with the DS469 regulation, focusing only on temperature requirements, with a minimum temperature of 20°C from 8am to 5pm on working days, no more than 100 hours above 26°C and no more than 25 hours above 27°C. If the requirements are not met, then the design is optimized using cooling devices such as shadings and natural ventilation. If these solutions still do not achieve the required levels, then mechanical cooling solutions needs to be implemented.

Once the final design satisfies the temperature requirements, the indoor environment and energy consumption of the model is studied in regard of DS469 and EN15251, to check if these standards are met as well. The two final models, with radiators or floor heating, are then compared in light of all considered parameters.

General

	Floor heating – Copenhagen	Floor heating – Oslo	Floor heating – Rome	Radiator heating – Copenhagen	Radiator heating – Oslo	Radiator heating – Rome
Design outdoor temperature	-12 °C	-23 °C	-1 °C	-12 °C	-23 °C	-1 °C
Design heat load	26,7 W/m²	34,4 W/m²	17,8 W/m²	529 W	820 W	353 W
Design cooling load	37,4 W/m²	39,9 W/m²	46,0 W/m²	741 W	791 W	912 W
Weather file	Värlöse Copenhagen TRY	Oslo/Fornebu_ASHRAE IWEC	Roma Ciampino TRY	Värlöse Copenhagen TRY	Oslo/Fornebu_ASHRAE IWEC	Roma Ciampino TRY
Cooling strategy	Natural cooling (shading and opening windows)	Natural cooling (shading and opening windows)	Mechanical cooling (floor cooling)	Natural cooling (shading and opening windows)	Natural cooling (shading and opening windows)	Mechanical cooling (cooling panel)

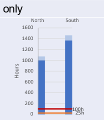
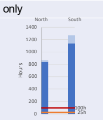
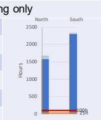
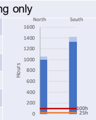
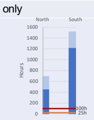
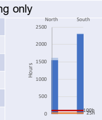
Indoor temperatures

DS 469

The DS 469 states the requirements that the indoor conditions of the building must have to ensure a comfortable environment for the occupants. The amount of hours with temperature over 26°C must be lower than 100, and lower than 25 for temperature over 27 °C, during the occupancy time of the whole year. In the first simulation run, no cooling system was implemented, and the requirements from DS 469 were not met. A simulation with shading and natural ventilation from the window let the requirement be met in Copenhagen and Oslo, but not in Rome where a mechanical cooling system was necessary. The results of the first simulations and of the one meeting the requirements are shown below.

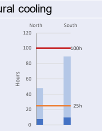
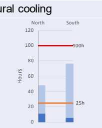
Heating only

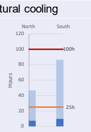
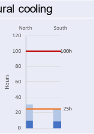
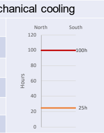
	Floor heating – Copenhagen	Floor heating – Oslo	Floor heating – Rome	Radiator heating – Copenhagen	Radiator heating – Oslo	Radiator heating – Rome
Heating setpoint	20 °C	20 °C	20 °C	20 °C	20 °C	20 °C
Opening windows setpoint	25.5 °C	25.5 °C	24.5 °C	25.5 °C	25.5 °C	24.5 °C
Max op.temperature (South)	40.5 °C	40.1 °C	45.6 °C	40.4 °C	36 °C	43.4 °C
Max op.temperature (North)	34.8 °C	34.1 °C	38.7 °C	35.1 °C	31.3 °C	37.2 °C
Min op.temperature (South)	20.9 °C	20.4 °C	23.9 °C	20.4 °C	20.1 °C	23.7 °C
Min op.temperature (North)	20.8 °C	20.8 °C	2 v0.8 °C	20.1 °C	20 °C	20.5 °C

Heating + natural cooling / Heating + mechanical cooling

	Floor heating – Copenhagen (Heating + natural cooling)	Floor heating – Oslo (Heating + natural cooling)	Floor heating – Rome (Heating + mechanical cooling)	Radiator heating – Copenhagen (Heating + natural cooling)	Radiator heating – Oslo (Heating + natural cooling)	Radiator heating – Rome (Heating + mechanical cooling)
Heating setpoint	20 °C	20 °C	20 °C	20 °C	20 °C	20 °C
Opening windows setpoint	25.5 °C	25.5 °C	24 °C	25.5 °C	25.5 °C	24 °C
Max op.temperature (South)	28.8 °C	27.8 °C	26.3 °C	28.8 °C	28 °C	25.1 °C
Max op.temperature(North)	28.1 °C	27.9 °C	26.5 °C	28.0 °C	28.1 °C	25.1 °C
Min op.temperature (South)	20.4 °C	20.4 °C	20.5 °C	20.4 °C	20.1 °C	20.7 °C
Min op.temperature (North)	20.6 °C	20.8 °C	20.8 °C	20.1 °C	20 °C	20.3 °C

- >27°C
- >26°C

As it can be observed from the "Heating only" chart, this option is not viable as building stays above 26 °C 12-14 times longer than allowed by regulations from DS 469. In order to fulfill the regulations, we set the cooling point from initially 26 to 25,5 °C. With this we could fulfill the regulations by only passive means (shading + window opening). As we can see from above – natural cooling is a sufficient option for both Copenhagen and Oslo.

With heating only option the Rome model has a temperature over 26°C 23 times longer than allowed by the regulation. In this case natural cooling was not enough and mechanical cooling had to be installed – which drastically improved the situation. As a result, the behavior of the system is really good and aligns perfectly to the regulations (both EN15251 and Ds 469).

As only passive means are used, control of the user is much higher than with mechanical cooling. The option to align the cooling to the working schedule also allows to have regular temperature levels but still enables the user to open the windows whenever they want. Furthermore, opening windows allows fresh air from outside to directly enter the building. This benefit is also recognized by comparing the CO2 levels of both passive and mechanical cooling, with a clear advantage for the passive solution (mean CO2: 565 ppm in CPH to 633 ppm in Rome).

In order to fulfill the regulations from DS 469, we set the cooling point from initially 26 to 24 °C. and applied mechanical cooling, as passive means were not sufficient. The best solution is to combine mechanical cooling with sun shading to prevent overheating. Opening windows is not possible anymore, as it would decrease the efficiency of the mechanical cooling significantly.

Energy performance

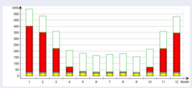
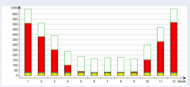
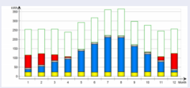
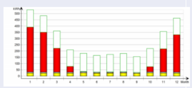
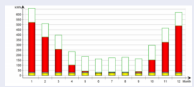
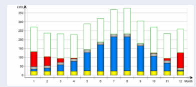
The energy consumption of the building is affected by several factors, such as number and activity of the occupants and electronic equipments. These are implemented in the simulation as internal heat gains with the following values:

- Occupants: 2 with an activity level of 2 MET (around 258 W)
- Lighting: 50 W
- Equipment 350 W

The **Building Regulation** (BR) states the maximum value of primary energy that a building can use to satisfy the needs for heating, cooling and lighting, called EPI (Energy Performance Index). The buildings have been analyzed according to the BR 2010, 2015, 2020 to check if the requirements were met. Some factors are used to convert the energy used into the corresponding primary energy.

Heating | Cooling | Lighting | Auxiliaries

	Floor heating – Copenhagen	Floor heating – Oslo	Floor heating – Rome	Radiator heating – Copenhagen	Radiator heating – Oslo	Radiator heating – Rome
Energy for heating	1467 kWh/y	2036 kWh/y	273 kWh/y	1440 kWh/y	2020 kWh/y	264 kWh/y
Energy for cooling	5 kWh/y	5 kWh/y	1098 kWh/y	5 kWh/y	5 kWh/y	1024 kWh/y
Energy for auxiliaries	108 kWh/y	108 kWh/y	121 kWh/y	108 kWh/y	109 kWh/y	183 kWh/y
EPI 2010	50.8 kWh/m²y	62,6 kWh/m²y	83,4 kWh/m²y	50,2 kWh/m²y	62,3 kWh/m²y	82.6 kWh/m²y
EPI 2015	44.7 kWh/m²y	54,1 kWh/m²y	82,3 kWh/m²y	44,2 kWh/m²y	53,9 kWh/m²y	81.5 kWh/m²y
EPI 2020	32.9 kWh/m²y	40,0 kWh/m²y	59,4 kWh/m²y	32,6 kWh/m²y	39,8 kWh/m²y	58.8 kWh/m²y

EPI and primary energy factors

Regulation	Max. EPI [kWh/m²y]	Heating	Electricity
BR2010	105,5 (71,3+1650/*Area*)	1	2,5
BR2015	61,7 (41+1000/*Area*)	0,8	2,5
BR2020	25	0,6	1,8

As it can be observed from the values presented above, the consumptions for heating and cooling vary a lot between the three locations. The coldest climate of Oslo makes it the location with the highest design heat load and consumption for heating (2036 kWh), followed by Copenhagen (1467 kWh) and Rome (264 kWh only). The consumption of energy of the floor heating system is generally slightly higher than the one with the radiator, as it can be observed in all the location. Nevertheless, it is important to highlight the higher indoor comfort of the floor system compared to the radiator and the lower temperatures of operation, which allows the use of more efficient energy sources, such as heat pumps or solar panels. As only natural cooling is implemented in the two Nordic cities, their consumption for cooling is negligible, while it is the main entry in Rome (1024 kWh), due to the mechanical cooling system necessary to lower the high temperatures of the Mediterranean climate. This affects also the power to operate the auxiliaries, as more energy is required to pump the cold water in the warm season. It can be observed that the floor heating system demands less energy for the auxiliaries compared to the cooling panel implemented in Rome with the radiator.

The buildings in Oslo and Copenhagen meet the requirements of the BR 2010 and 2015 but not the strict low-energy buildings regulation of 2020. On the other hand, Rome does not meet the requirement of 2015, due to the fact that most of its consumption is electric power for the cooling system (70%), whose primary energy factor is higher than the one of district heating and it does not decrease between 2010 and 2015.

Indoor environment

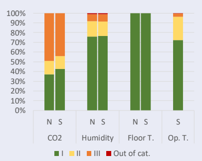
- Category I
- Category II
- Category III
- Out of categories

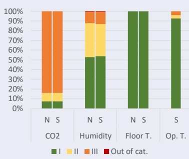
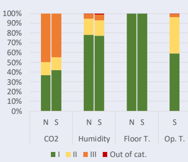
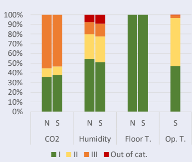
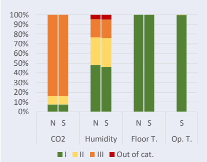
CO2:
- 400+350 ppm
- 400+500 ppm
- 400+800 ppm

Floor temperature:
- 19-29°C
- 19-29°C
- 17-31°C

Humidity:
- 30-50%
- 25-60%
- 20-70%

Air temperature
- 21.5 - 25.5 °C
- 20 – 26 °C
- 19 – 27 °C



Floor heating:

Copenhagen CO2 N	CO2 S	Humidity N	Humidity S	Floor T. N	Floor T. S	Oslo CO2 N	CO2 S	Humidity N	Humidity S	Floor T. N	Floor T. S	Rome CO2 N	CO2 S	Humidity N	Humidity S	Floor T. N	Floor T. S
III	III	Out of cat.	Out of cat.	I	I	III	III	Out of cat.	Out of cat.	I	I	III	III	Out of cat.	Out of cat.	I	I

Radiator heating:

Copenhagen CO2 N	CO2 S	Humidity N	Humidity S	Floor T. N	Floor T. S	Oslo CO2 N	CO2 S	Humidity N	Humidity S	Floor T. N	Floor T. S	Rome CO2 N	CO2 S	Humidity N	Humidity S	Floor T. N	Floor T. S
III	III	Out of cat.	Out of cat.	I	I	III	III	Out of cat.	Out of cat.	I	I	III	III	Out of cat.	Out of cat.	I	I

Conclusion

Temperature (DS469 and EN 15251)

The ideal temperature in an indoor environment is between 20°C and 26°C. The first simulation with only a heater resulted in much higher temperatures for long time spans (for example 2400h in Rome with floor heating where there should not be more than 100h), which was unacceptable.

After applying the natural cooling solutions to the models (external blinds, window opening during the working hours at a cooling setpoint temperature of 25,5°C), or mechanical solutions when needed (in Rome, floor cooling or cooling pannels with a setpoint of 24°C) the requirements were met in every model.

However, both systems are very similar regarding their temperature results. The main difference remains that the cooling pannels in Rome is more efficient temperature-wise when compared to floor cooling, as temperatures over 26°C are never reached, because cooling pannels have less inertia. On the other hand, floor cooling is more energy efficient.

Energy Performance (BR)

The buildings in the three locations have different behaviors under an energy point of view, reflecting the different climates they have to adapt the indoor temperature to. We can see similar patterns in Copenhagen and Oslo, with significant higher heat consumption in the latter due to the colder climate. This results in the EPI of the building in Oslo being around 23% higher than the one in Copenhagen. Both buildings are meeting the regulations of BR2010 and 2015 but not the one of 2020.

A different situation is for the building in Rome, where the major consumption is caused by cooling, with low consumption for heating. This determines a higher EPI in Rome, due to the higher primary energy conversion factor of electricity compared to the one of district heating. This results in an EPI of the building in Rome around 64% higher than the one in Copenhagen.

The consumptions of the floor heating system are generally slightly higher than the ones of the radiators-based system. Also the floor cooling system has higher consumption than the cooling panel in Rome. Nevertheless, the cooling panel requires more energy from the auxiliaries, which offset the energy for the emission system only. Furthermore, the floor systems creates less dishomogeneity in the surface temperatures of the room, resulting in more comfort and less convection.

Indoor Environment (EN 15251)

Comparing the indoor environment for all locations and systems, the most significant difference can be recogniced between the nordic cities and Rome as the cooling system is different. With openable windows, the CO2 level in the air is much lower resulting in 40% of the time in category I, compared to less than 10% of the time in category I for mechanical cooling.

The humidity requirements in all locations are not fulfilled. However, Copenhagen has a better humidity level than Oslo, probably as the climate is warmer, resulting in more time with open windows in summer. In Rome, the windows are never open, resulting in a lower humidity comfort level. In this case, floor heating is slightly better as it provides more homogeneous temperature.

For the floor temperature, both systems are within category I at all times of the schedule, although the floor heating provides a warmer floor in winter and has a higher risk of overheating in summer.

In general, both systems are almost equal in their indoor quality and only minor differences can be recognized. The advantage of the floor heating is that temperatures in the room are more homogeneous than with a radiator and furthermore it reduces the convection in the room, but these parameters are not investigated in this study.

Behavior of the System/ Control

In order to fulfill the regulations from DS 469 in Oslo and Copenhagen, we set the cooling point from initially 26 to 25,5 °C. With this we could fulfill the regulations by only passive means (shading + window opening). In order for the system to stay under 26°C, the cooling system needs to have a buffer of 0,5 °C. The results from both systems are almost similar with slightly more overheating with the floor heating. This may be caused by the slower reaction time of the system.

Floor heating in general has lower control for the users compared to radiators, but especially for an office building, aligning the heating system to the working schedule allows to get smooth and regular temperature levels which are within the regulations. If mechanical cooling has to be applied, controllability for the user is lower than with openable windows. The cooling is aligned to the working schedule and therefore delivers comfortable temperatures when the building is occupied, although it clearly lacks user control.