

Exploring easy-implementable adaptation strategies to climate change scenarios of existing office buildings: a case study in the Swiss context

Sergi Aguacil Moreno¹, Cecile Anne Berquand², Verena Marie Barthelmes², Dolaana Khovalyg¹
¹Building2050 group, Ecole polytechnique fédérale de Lausanne (EPFL), Fribourg, Switzerland

²Thermal Engineering for the Built Environment Laboratory (TEBEL), Ecole polytechnique fédérale de Lausanne (EPFL), EPFL Fribourg, Switzerland

Abstract

European energy policies are aimed at increasing the climate resilience of infrastructure, including new and existing buildings. The implications of future ambient conditions on the energy and environmental performance in buildings and respective adaptation strategies still need to be thoroughly investigated. The aim of this simulation-based study is to estimate the effect of selected future weather scenarios by the Intergovernmental Panel on Climate change (IPCC), on the energy demand of a Swiss office building. The results showed that the cooling demand can increase up to 146% in future scenarios. Finally, some preliminary alternative design and operational solutions were explored to enhance building resilience to climate change.

Key Innovations

- A simulation-based study to estimate the impact of future climate change scenarios in the context of an office building located in the Swiss context.
- Preliminary exploration on how the design of different space layouts and easing temperature set points in certain zones might increase the climate robustness of the simulated case study.

Practical Implications

This study should serve as an explorative example for practitioners and architects, and stress the importance of a climate-resilient building design and operation in view of inevitable future climate changes.

Introduction

Buildings are complex architectural and engineering systems that should provide throughout their lifespan a comfortable indoor environment for living and working. Typically, prior to the actual construction, performance of buildings is evaluated using energy simulation tools by considering typical meteorological year (TMY). Such an approach lacks consideration of climate change and the challenge of increasing energy use of existing buildings to adjust to outdoor environmental changes (United Nations Environmental Program, 2007). Exploration of the resiliency and possible adaptation strategies that can keep energy requirements at the current level is especially important for existing buildings that were designed using

TMY weather data without accounting for the potential future climate effect on energy demand.

Resiliency in the engineering field is defined as the ability of systems to adapt positively in the presence of a disturbance and unpredicted changes (Scharte et al. (2014), Holling (1973), Hollnagel et al. (2006), Hosseini et al. (2016)). While the effect of the climate change on the energy demand of buildings has been gaining increased attention in the literature, there is a lack of relatively easy-implementable propositions on how the existing buildings should cope with such a disturbance.

For instance, Frank (2005) analysed the impact of climate change on heating and cooling energy demand in selected building types in Switzerland; variation of the insulation value was also considered in the parametric study. Since the number of cooling days increases and the number of heating days decreases due to climate change, an increase in cooling energy demands up to 1'050% in the time horizon 2100 was reported. However, the work did not propose any adaptation strategies for buildings to cope with increased energy use for cooling, except for improving the building envelope. A detailed analysis by Domínguez-Amarillo et al. (2019) on the performance of Mediterranean buildings in scenarios involving climate change includes retrofitting of the building envelope as well to counteract the increasing energy demand.

There are some more publications such as by Kalvelage et al. (2014), Nik V.M. et al. (2015) and Rajkovich et al. (2019) focusing on the robustness of the design decision exploring different construction scenarios, but they are applicable to new construction or deep-renovations. This work, along with the exploration of the effect of climate change scenarios on the global energy performance, proposes low-cost and easy-implementable strategies such as acting on the setpoints, layout, and re-distributing functionality of zones to help facility managers to maintain the energy performance at the level of 2020 (or even improve) considering the future climate scenarios.

Methodology

Using a case study, a series of purely operational actions is proposed, such as the variation of the setpoint temperatures or the modification of the layout and the type of use of different indoor spaces. For each strategy, the energy demand and the thermal balance is calculated. The final objective is to evaluate the impact of these

strategies, which can be easily implemented in a relatively recent building that would not admit a deep renovation of his envelope or its HVAC systems.

Case study building

This study is based on dynamic energy simulations (DesignBuilder, 2020) of a mixed-mode ventilated office building located in Lausanne, Switzerland, in the Swiss climate zone 5 (SIA, 2010). The 5-storey office building has a net-conditioned floor area of 4'184 m² and was built in 2010 according to Minergie standard (Minergie, 2020). It is part of a set of a building complex with five-storey cubes at a length of 30 meters (Figure 1). Is a recent building with an efficiency level better than the average of buildings of the same period due to the additional energy performance requirements of a building located on a university campus / research centre. It is a building that could be more efficient but a deep renovation of the envelope (e.g. adding more insulation) is neither economically nor environmentally justifiable.



Figure 1: Design Builder model.

All the floors are composed of a circulation area, private, shared and open space offices, as well as meeting and conference rooms (Figure 2). The building envelope' features are summarised in Table 1.

Table 1. Building envelope' features

Component	Settings
Flat roof	U-value 0.124 W/m ² .K
External wall	U-value 0.178 W/m ² .K
Indoor partitions	U-value 0.667 W/m ² .K
Ground floor	U-value 0.210 W/m ² .K
Aluminium-framed windows with triple pane (3.6 m of width and 1.7 m height)	U-value: 0.6 W/m ² .K, Solar Transmittance: 50%, Lighting Transmittance: 75 %
Window frames	U-Value: 3.60 W/m ² .K
General air tightness	0.3 ACH

To control solar gains and avoid overheating problems, all windows in the building are equipped with external solar shading systems (vencian blinds) which can be activated manually or automatically. In this case it has been assumed that the occupants of the building will lower the blinds if the interior temperature exceeds 24°C. This setpoint temperature has been taken as the setpoint for the control of the solar shading system in order to act in a preventive way and to avoid as far as possible to reach

26°C (temperature considered as the temperature above which the cooling system needs to be activated).

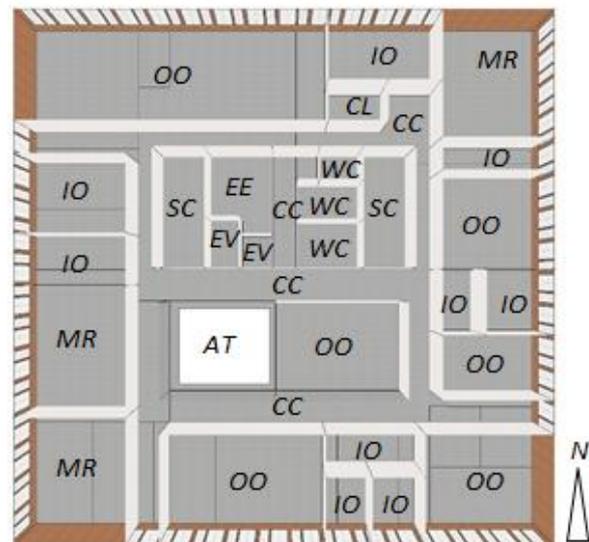


Figure 2: Example of a floor plan (Floor 3) with the repartition of thermal zones related to the indoor activity: Individual Office (IO), Open Office (OO), Meeting Room (MR), Cleaning Facilities (CL), Toilet (WC), Staircases (SC), Elevator (EV), Corridor/Circulation (CC), Electric Equipment (EE) and Atrium (AT).

Space heating and cooling is provided by a hydraulic radiant ceiling panel system. This study is focused on exploring impacts of different weather scenarios on heating and cooling needs. However, the HVAC system is completely modelled. The building is connected to a district-heating system based on water-water heat pumps that exchange energy with Lake Geneva to cover the energy needs for heating, cooling and domestic-hot water (DHW). Ventilation is provided by an air-handle unit with heat recovery. The simulation input for heating/cooling temperature set-points (21°C/26°C for office spaces) and space usage (e.g. schedules for electric equipment, lighting, and occupancy) are set according to SIA 2024:2015 (SIA, 2015) and defined for the different zone typologies (single office, open space office, meeting room and circulation area), respectively. Information on power densities for electric equipment and lighting, as well as occupancy densities can be found in Table 2.

Table 2: Space usage for different spaces taking as a reference the SIA 2024:2015 (SIA, 2015).

Zone typology	Heating/cooling set-points (°C)	Electric equipment Power density (W/m ²)	Lights Power density (W/m ²)	Occupancy Density (m ² /person)
Single office	21/26	3	11.6	20
Open office		4	9.1	10
Meeting room		1	11.6	20
Circulation area	20/--	2	7	10

Weather scenarios

The aim of the project is to study how a current building will behave with climate changes through the years. The implemented weather scenarios were defined by the Fourth assessment of the Special Report on Emissions Scenarios (SRES) published by Intergovernmental Panel on Climate Change (IPCC, 2000). A range of 6 scenarios was established, and all regrouped in 4 different families A1, A2, B1 and B2 (Figure 3). The purpose of this intergovernmental organization is to provide policymakers with scientific information concerning climate change regularly. These reports treat different scenarios to show how different economic, political choices could affect the human-induced climate change.

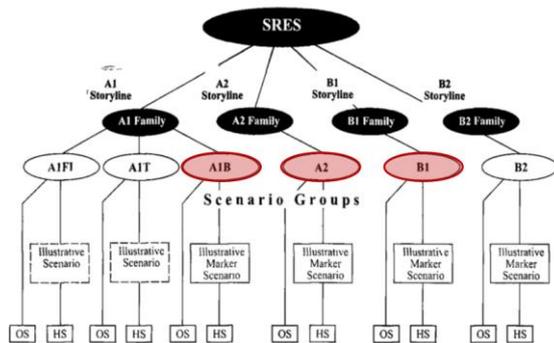


Figure 3: Scheme of selected weather scenarios (in red) from SRES (Special Report on Emissions Scenarios) published by IPCC. Adapted from (IPCC, 2000).

The scenarios differ according to the evolution of the population and economical choices, however they all have the same probability of occurrence. In our case we will study the scenarios A1B, B1 and A2 (Figure 3), the artificial weather files used to conduct energy simulation are generated using Meteonorm 7.2 (Meteonorm, 2019).

It is to note that the latest IPCC scenarios (Representative Concentration Pathways - RCP) that were published in 2014 (REF) were not yet available in the climate file software at the time of the study. Although the RCP and SRES scenarios differ slightly (Rogelj J. et al., 2012 and Farag A. et al., 2016), we believe that for the purpose of the article the use of the SRES scenarios is sufficient to show the impact of the easy-implementable strategies (temperature setpoints and layout / type of usage modifications). The features of the three climate scenarios are detailed here:

- **Scenario A1B** is in the A1 family. This one is characterised by a future world with a rapid economic growth and a rapid introduction to new and more efficient technologies, there is also a population growth with a peak at the mid-century and then a decrease of the population. The major theme will be the reduction of differences between populations leading to a more homogeneous world. This will take place through the convergence among regions, increase of cultural and social interactions, with a reduction in regional differences in per capita income. The letter in this family

of storyline characterised the technology which will be emphasised. However, in the case A1B there is a balance across resources so that there is not a particular one that is too heavily relied on.

- **Scenario B1** describes as the previous one a peak of the population mid-century and then a decrease of the population. However, in this case there is a rapid change in the economy toward a service and information economy with a reduction in material intensity and the introduction to clean and resource-efficient technologies. Finally, this scenario defines a more homogeneous world with a search for an economical global solution, sustainability, equity and climate initiatives.

- **Scenario A2** describes conversely to the other a heterogeneous world with a regionally oriented economic development and preservation of local identities. The economic growth is slower and more fragmented than in the other scenarios. Finally, the population is constantly increasing.

The impact of the technology on the emission of gas is well known but the scenarios also take into account the evolution of the population growth. The emissions are less important in scenario B1 because there is a rapid introduction to more “clean” and resource efficient technologies. Generally, emissions have an impact on global warming which leads to an increase of the temperature and a decrease of the solar impact. Figure 4 represents the global warming evolution for the different scenarios. As expected, the least optimistic scenario A2 results in the highest temperature increase of 3.4°C (likely range of 2.0-5.4°C). Conversely the most optimistic scenario B1 results in a temperature of 1.8 °C (likely range of 1.1-2.9°C) which is still a significant change. Scenario A1B results in a change of 2.8°C (likely range of 1.7-4.4°C).

These global surface warming have also a heavy impact on the solar impact since it increases the water cycle. As mentioned in the report of working group I of IPCC: “Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3’000 m and that the ocean has been absorbing more than 80% of the heat added to the climate system. Such warming causes seawater to expand, contributing to sea level rise”. This rise is due to the melt of the ice and it highly influences the average atmospheric water vapour which has been increasing since at least the 1980’s according to the report.

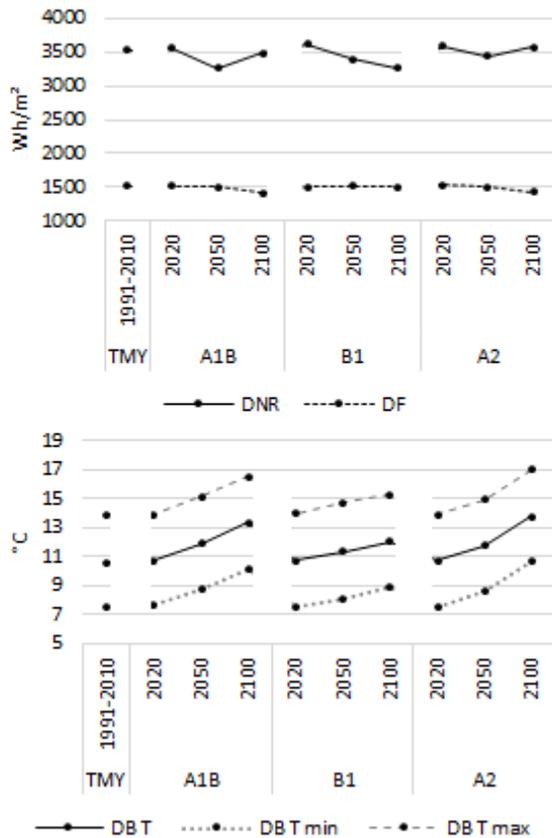


Figure 4: Dry-bulb temperature (DBT), direct normal radiation (DNR) and diffuse radiation (DF) of the different weather files and horizons.

Results

To evaluate the evolution of the case study building's heating and cooling needs, ten different scenarios assuming different outdoor environmental conditions were simulated.

The three described weather scenarios (A1B, B1 and A2) were analysed for 2020, 2050, and 2100 horizons, respectively, and compared to the *baseline* scenario, in which historical weather data (1990-2010) for a typical meteorological year (TMY) is used. The results of the evolution of the energy demand for space heating and cooling are shown in Figure 5.

The evolution of the heat balance for a typical heating and cooling month are shown in Figure 6, highlighting the expected increasing emission of gas will have an effect on a rising outdoor temperature and a decrease of solar heat gains (especially in scenario A2).

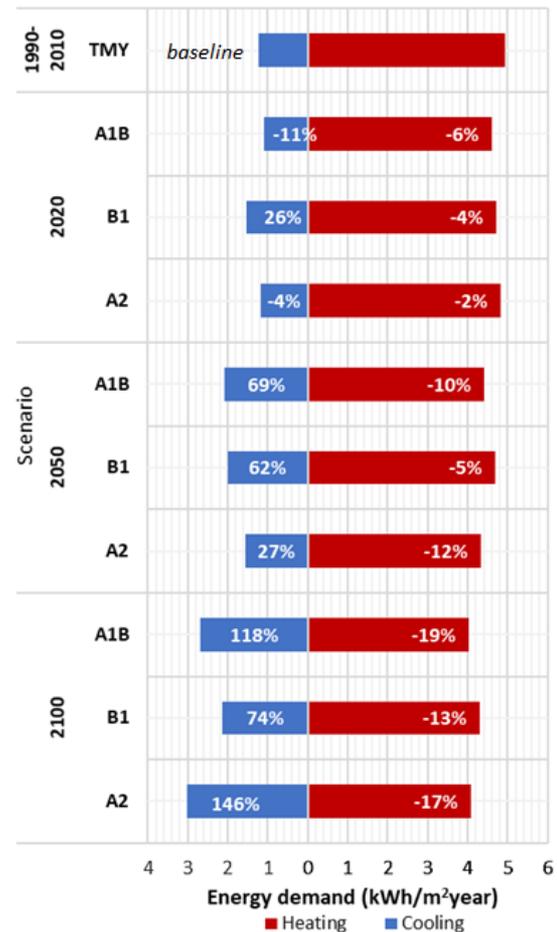


Figure 5: Evolution of the building energy demand through different years and for different weather scenarios.

Table 3: Comparison of the outdoor DBT (dry bulb temperature), total direct normal radiation (DNR) and diffuse radiation (DF) between the baseline (TMY) and critical scenarios (A1B and A2) for 2100 horizon.

	January			July		
	DBT (°C)	DNR (kWh)	DF (kWh)	DBT (°C)	DNR (kWh)	DF (kWh)
TMY	1.25	48.7	22.3	20.24	166.6	80.16
A1B	3.87	36.2	19.4	24.04	220.1	69.01
A2	3.98	40.6	18.6	25.06	214.7	72.55

The overall tendency through the years is an increase in cooling needs (with clear evidence starting from 2050) and a decrease in heating needs (Figure 5). The results show that the highest variation with respect to the baseline scenario can be observed for the year 2100, in particular in scenario A1B for heating energy demand (-19%), and scenario A2 for cooling energy demand (+146%). We therefore consider these two scenarios as "extreme" scenarios. Table 3 highlights that the outside dry bulb temperature is about one degree higher in scenario A2 with respect to scenario A1B during July, which implies increased cooling needs. Indeed, the most "critical" scenario is scenario A2-2100 since it increases the building energy demand to the largest extent. This

scenario was therefore used for further analysis to explore the building energy performance and the distribution of heating and cooling needs across different floors identifying the most critical ones during heating and cooling period. In particular, Table 4 highlights that, in scenario A2-2100, Floor 2 mostly impacts the energy demand for space heating (24%), while Floor 3 has the biggest impact on the energy demand for space cooling (23.52%).

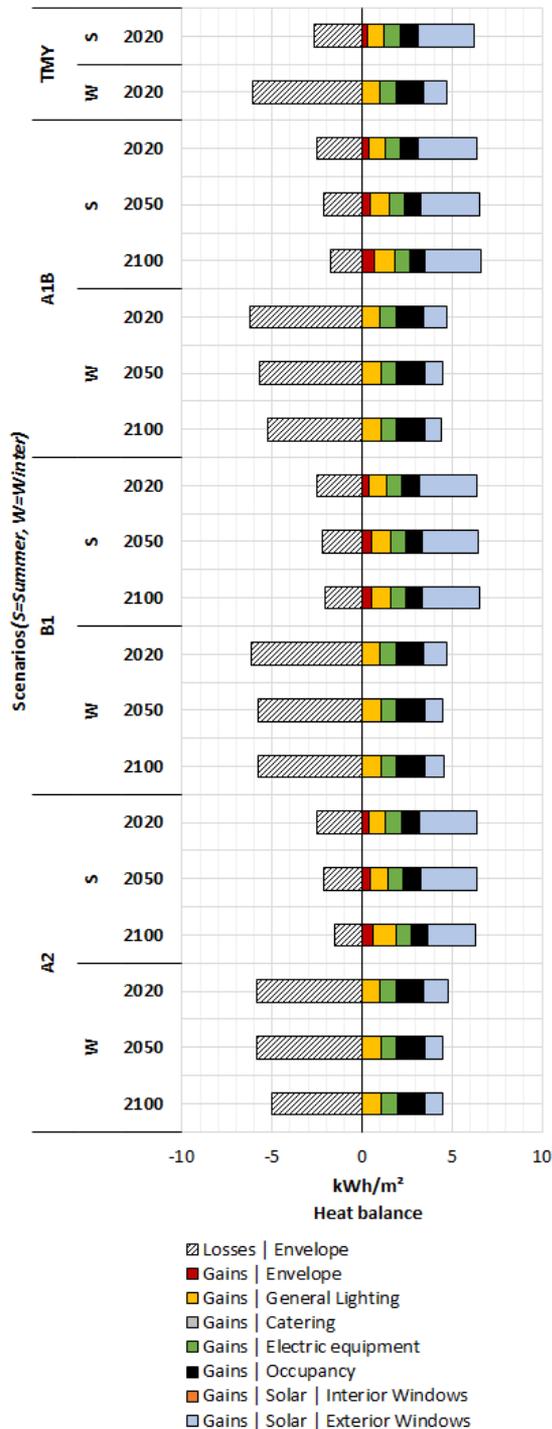


Figure 6: Evolution of the heat balance through different years and for different weather scenarios during one winter (January) and summer month (July).

Table 4: Critical scenario A1 for 2100 horizon: cooling and heating needs for different floors.

	Heating needs (kWh/m ² y)	% total heating needs	Cooling needs (kWh/m ² y)	% total cooling needs
Building	4.09		3.18	
Floor 0	0.85	20.8	0.48	15.2
Floor 1	0.63	15.4	0.66	20.8
Floor 2*	0.98	24.0*	0.66	20.7
Floor 3**	0.71	17.5	0.75	23.5**
Floor 4	0.91	22.4	0.63	19.8

*critical floor during heating period

**critical floor during cooling period

Discussion

The results highlight that the different weather scenarios have a significant impact on the building energy needs in the upcoming century. It is therefore essential to start exploring different adaptation strategies that might increase the resilience of the building in view of inevitable climate change effects.

To explore possible solutions to mediate the effect of the climate change on increasing energy demands for space cooling in the critical scenario A2 for 2100 horizon, further simulations were done by identifying the critical floors during heating and cooling seasons and by assuming the following variations (Table 5) :

- (i) **Operational** - Variation of the temperature set-point for space heating and for space cooling
- (ii) **Design layout** - Variation of the thermal zones' boundaries/partitions by dividing or merging spaces (Fig. 7 and 8)
- (iii) **Combination** of variations proposed in (i) and (ii)

Table 5: Exploration of alternative design scenarios as potential adaptation strategies to climate change effects.

	(i) Operational	(ii) Space layout	(iii) Combination
Heating season	Reduction of the heating set-point from 20°C to 19°C in the circulation area	Division of the circulation area into smaller spaces (Figure 7)	of (i) and (ii)
Cooling season	Increase of the cooling set-point from 26°C to 27°C in all areas	Merging of single offices into larger open space offices (Figure 8)	of (i) and (ii)

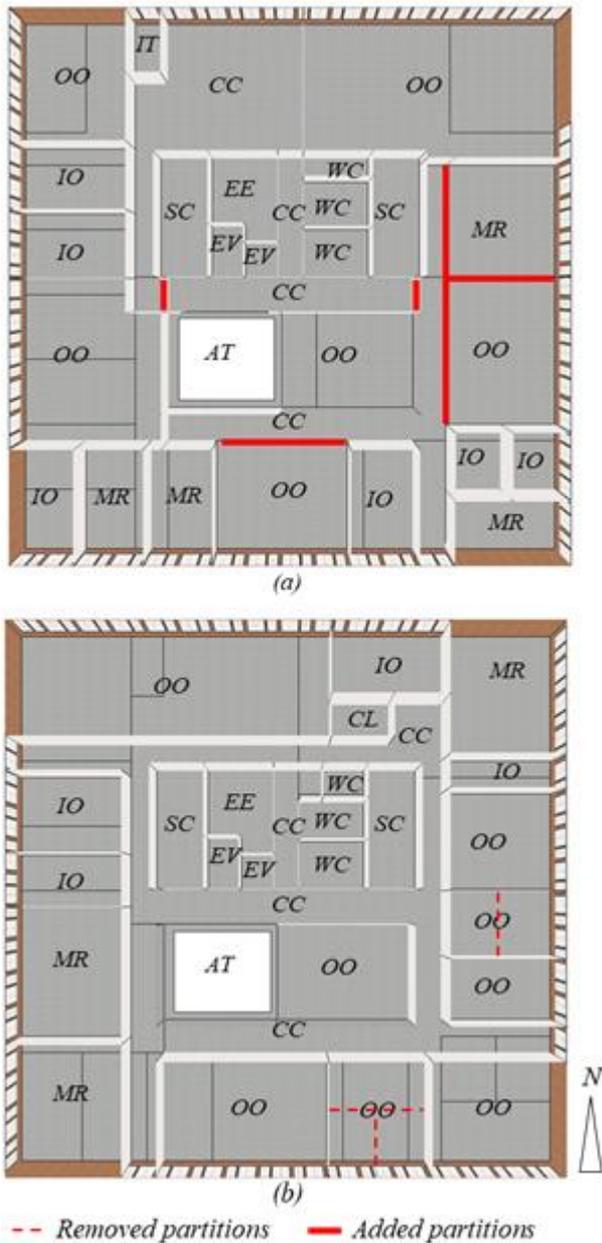


Figure 7: Alternative design layout for the critical floor heating season. (a) Floor 2 - Division of the circulation zone into smaller spaces and (b) Floor 3 - Merging of single offices into larger open space offices. Individual Office (IO), Open Office (OO), Meeting Room (MR), Cleaning Facilities (CL), Toilet (WC), Staircases (SC), Elevator (EV), Corridor/Circulation (CC), Electric Equipment (EE) and Atrium (AT).

Critical floor during heating season

Figure 8 shows that the variation of the zone partitions (Figure 7a) (ii), or rather the division of the circulation zone into smaller spaces, allows to achieve more significant energy savings (-24.72%) with respect to operational changes (i) of the temperature set-point (-5.07%). Further, at the specific floor level, this modification leads to the complete elimination of heating needs. If the two alternative design scenarios are

combined, it is possible to reduce the total energy demand for space heating of the building by 26.67%. It is important to mention that the variations were made on one floor only; further investigation could include how modifications of the space layout of the entire building might affect the building energy demand.

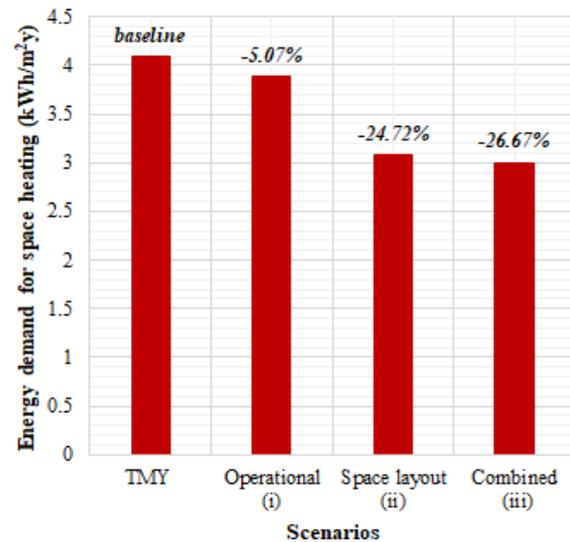


Figure 8: Impact on building energy demand for space heating of alternative design/operation scenarios.

Critical floor during cooling season

The impact of the alternative design scenarios during cooling season are shown in Figure 9. In contrast to the alternative heating scenario, the most significant energy savings can be achieved by increasing the cooling set-point from 26 to 27°C (-17.89%), while the change of the space layout (Figure 7b) allows for achieving reduced energy savings (-1.05%). In combination, the two design scenarios allow for reducing the total energy needs for space cooling by -18.67%.

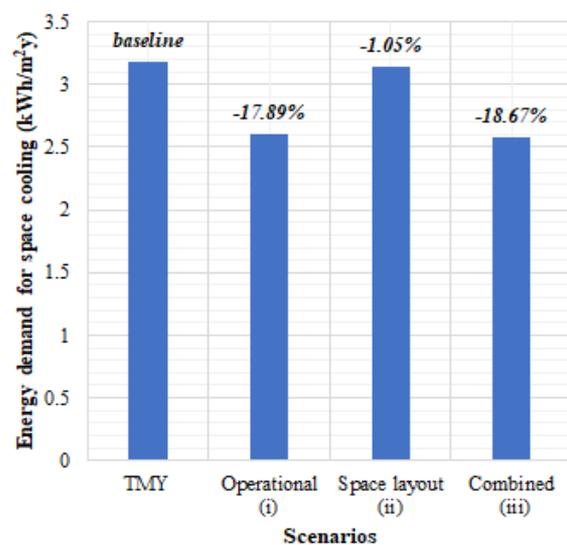


Figure 9: Impact on building energy demand for space cooling of alternative design/operation scenarios.

Since adaptation strategies seem to be particularly important during future cooling seasons and the increase of the temperature set-points for space cooling was found to be an effective strategy, the same has been applied to the other climate scenarios for the 2100 horizon. The outcomes (Table 6) show that an increase of the cooling setpoint can lead to an important reduction of energy demand in all scenarios (up to -32.54% in scenario B1 and up to -33.07% in scenario A1B, respectively).

Table 6: Reduction of heating/cooling needs for the operational adaptation strategy (i) - variation of the temperature set-point for all scenarios (2100 horizon).

	Assumptions for heating/cooling set-points	Heating needs (kWh/m ² ·y)	Cooling needs (kWh/m ² ·y)
A2	SIA 2024 (20*/26°C)	4.09	3.18
	Scenario (i) (19/27°C)	3.88	3.0
	Δ%	-5.07%	-17.89%
A1B	SIA 2024 (20*/26°C)	4.01	2.68
	Scenario (i) (19/27°C)	3.81	1.79
	Δ%	-5.00%	-33.07%
B1	SIA 2024 (20*/26°C)	4.23	2.14
	Scenario (i) (19/27°C)	4.13	1.44
	Δ%	-5.07%	-32.54%

*temperature set-points for space heating in circulation areas according to SIA 2024:2015

Conclusion

In this simulation-based study, we explored the evolution of cooling and heating needs of a Swiss case study building through three different years (2020, 2050, 2100) assuming different climate scenarios provided by the Intergovernmental Panel on Climate Change.

The results highlight that the increase of the building energy demand for cooling needs to be carefully tackled in future design practices in order to possibly mitigate climate change effects on building energy use. The weather scenarios have all shown that in the future the temperature will rise and there will be more atmospheric vapour leading to less solar impact.

These climate changes will induce a reduction of the building's heating needs and a drastic increase of the building's cooling needs. In fact, in the best-case scenario the increase of cooling needs is approximately 74% and in the worst case the increase is 146%. Furthermore, the building studied is recent, hence its insulation for external walls and openings are quite effective.

Since a typical lifespan of buildings can exceed 60 years (SIA 2023, 2010), the building will actually be exposed

to weather conditions around 2050 while the increase of the cooling needs is already significant at this stage. This highlights the fact that the energy design performances of buildings usually tested for historical data, should be tested with the future predictions in order to adjust the building to changes.

We performed some preliminary explorative solutions on how space layout or environmental operations can contrast the increasing energy demand, especially during cooling season. While during the heating season the variation of the space layout allowed to achieve more significant energy savings (-24.72%), during the cooling season the variation of cooling set-points seemed to have a bigger impact (-17.89%). Certainly, a limited number of possible adaptation strategies were investigated in this work and the analysis can be extended to more complex solutions (e.g., the application of passive cooling methods or solar shading control systems) towards improving building resilience to climate change, based on the most recent IPCC scenarios (Rogelj J. et al., 2012 and Farag A. et al., 2016). Further work is also needed to explore the effect of future climate scenarios in combination with different adaptation strategies not only on building energy performance, but also on the indoor environmental quality and well-being of building occupants.

Acknowledgement

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