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Effectiveness of passive climate change adaptation measures in Switzerland: A climate-based analysis on natural ventilation and overheating risks reduction in dwellings

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Abstract. Building energy codes have been implemented in Switzerland as well as across the world to reduce building energy consumption, however, due to the progressive effect of climate change phenomena and the precipitate change in occupancy patterns due to the global pandemic, their effectiveness and limitations must be constantly re-examined. This paper explores the effectiveness of natural ventilation as a passive cooling strategy, as well as the overheating patterns in dwellings across the Swiss territory. The work is based on a climate-based simulation model at a territorial scale, from which the building performance is further analysed considering the heating energy consumption and overheating risk hours above 26.5°C. The effectiveness of natural ventilation through the operable window operable area in reducing overheating risk was also estimated. The results show the effectiveness across the whole territory of the current regulation (SIA 380/1:2016), which is focused on the performance of the building envelope to reduce heat losses. An unattended alarming overheating pattern was spotted in locations with altitudes below 1500 meters as a direct consequence of the climate change phenomena, hence a series of recommendations are proposed to update and improve the current legal requirements.

Keywords. building energy codes, climate change, adaptation, energy performance, overheating risk

1. Introduction

As part of the global efforts to reduce Greenhouse gas (GHG) emissions, building energy efficiency programmes have been implemented across the world. In Switzerland, they were initially implemented during the 80s, and they have been gradually progressing together with the international standards. Considering the historical weather conditions in the Swiss territory, the normative presents a robust and elaborated set of rules, focused on decreasing the energy expended in space heating, whilst the use of active cooling systems are strongly discouraged. The building stock in Switzerland is made up of 75% residential buildings. According to the Federal Statistical Office (FSO), more than 60%, were built before the 80s, and less than 20% of dwellings were built under the current building energy code SIA 380/1:2016 [1]. Even though more people are living in multi-family buildings, the number of buildings occupied partially, or totally as single-family dwellings is greater [2].

Nowadays, after the appearance of the SARS-CoV-2 coronavirus disease, and the adoption of remote-working as a habit, there has been a considerable increase in the time spent at home. This new "atypical occupation", significantly differs from the standardised occupation pattern defined by SIA 2024:2015 [3], and as a consequence, the interior quality of the domestic spaces is being scrutinized, together with the possible areas of improvement within building standards. Two of the most discussed aspects of the indoor environmental quality (IEQ) are natural ventilation and thermal comfort, given the airborne nature of the new virus, combined with the constant effect of Climate Change (CC) [4].

Due to the geography of the Swiss territory, the effects of CC can be differently perceived across regions. The potential risk of overheating is greater in the Swiss Plateau and the Southside of the Alps. The first one is the region located between Lake Constance and Lake Geneva, at an altitude below 600 meters above sea level. Although this region accounts for only 30% of the Swiss territory, it hosts over two-thirds of the Swiss population and the metropolitan areas of Zurich, Geneve, Basel, Lausanne, and Bern. These two regions present the highest summer temperatures, a significant increase above 2°C has been observed over the last 30 years due to CC. Furthermore, a projected annual increase of at least 2-3°C is expected for the next decades [5]. In addition, these two regions also show the highest morbidity and mortality ratios in the country as a consequence of heat-stress related health issues during the summer. Recent studies conducted by M. Ragettli [6] have found a direct correlation between the occurrence of heatwaves and emergency hospital admissions, concluding that high temperatures have been a considerable risk factor for human health in Switzerland since, at least, the year 2003.

The present work is centred on evaluating the effectiveness and limitations of the current building regulations, as well as the variation of its effect across Swiss regions. This research looks into the potential of Natural Ventilation (NV) to prevent overheating. Considering that the Swiss building normative can be interpreted as a prescriptive set of rules that is equally applied to the whole territory varying only in the admissible amount of energy for space heating, this research includes the whole Swiss territory with the interest of gaining a better understanding of the influence of the Swiss normative at the different climate conditions in the country.

2. Methodology

The Swiss Society of Engineers and Architects (SIA) proposes a specific method to calculate the environmental performance of any given building [1,3,7,8]. This method uses specific climate data as well as the software tools for the process, however, in this investigation, and with the interest of developing a more detailed and accurate analysis, the weather data was replaced with newer and interpolated data, moreover, EnergyPlus was used to conduct dynamic building energy simulations.

2.1. Weather Data

As a first step, a theoretical grid of 25km by 25km was laid above the Swiss territory and a series of points were placed at the centre of each of the spaces of the grid, the objective was to create a series of study points equidistant and evenly distributed (Figure 1). The altitude and yearly average temperature of each point can be appreciated in Figure 2. The climate data provided by the SIA for the purpose of building performance calculations, corresponds to a 30-year period, from 1984 to 2003 [8]. Following the newer specifications of the World Meteorological Organization [9] concerning the use of recent data to accurately account for Climate Change, a newer 20-year period encompassing the years 2000 to 2019 was utilized.

The weather data was generated as EPW files for building simulations. They were produced using the interpolation function in the software Meteonorm 8. Following this process, weather datasets were generated for each point of the grid considering the information from the nearest weather stations as well as the calculated radiation for the actual location [10]. Some of the grid points that felt out of the Swiss territory were preserved since they were no more than 20km away from the border and it is understood that climate variation within this range can be considered minimum [10]. Finally, a total of 96 weather datasets were created, containing the necessary climatic inputs for subsequent building thermal simulations.

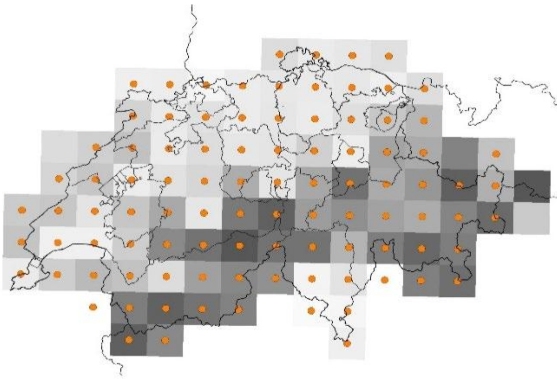

Figure 1. Equidistant grid for study points at a resolution of 25km by 25km.

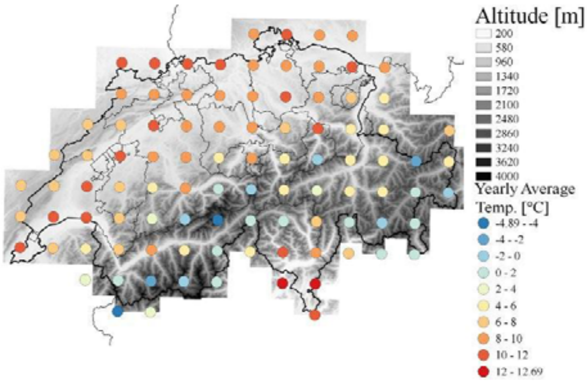

Figure 2. Study points with the contextual elevation and the yearly average temperature.

2.2. Building Elements and indoor conditions

A 3D building energy model (BEM) was elaborated following the specifications from building regulations as well as the national statistics regarding spatial standards. This included the dimensioning of the spaces, windowed surface areas and the application of solar protection. The objective was to create a digital model capable of representing the typical Swiss single-family house. Following national statistics data, the house has a rectangular floorplan, two stories, and a gable roof. It was configured in a sub-urban context, with windows placed only on the North and South main façades. Additionally, according to what is most commonly found in contemporary and vernacular architecture, a balcony was placed in the south façades and an overhang of the roof of 0.40m was considered (Figure 3). Given that neither the Swiss normative nor national statistics contain any information with regards to the amount of glazing or Window to Wall Ratio (WWR), a value of 60% was assigned to the North and South façades. In Table 1, all the physical details of the model are presented.

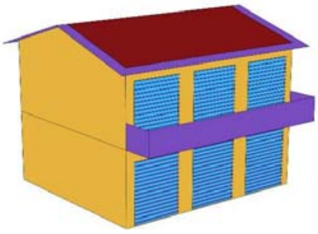

Figure 3. Building energy model

Table 1. Main geometrical features.

Floor area	100 m²
Floor perimeter	28,4 m
Volume	270,2 m³
Interior Height	2,7 m
WWR South	0,6
WWR North	0,6
WWR East	-
WWR West	-

WWR: Window to Wall Ratio

The internal conditions were designated following the normative [3]. The values for internal loads as well as occupancy patterns, equipment, and lighting were followed according to the specifications including mechanical ventilation providing a fresh air flow of 0.6 m³/(m²h). The solar protection was designed covering 100% of the glazing areas even though the normative only requires only 50% of the surface, also, it was considered on the exterior of the building, despite of the fact that the normative does not specifies its location. The building material specifications, such as thermal properties and construction systems were also chosen following the corresponding standards [1, 3, 11], in all the cases, the building envelope was considered composed by 12cm the terracotta brick commonly found. During the summer months, Natural Ventilation was utilized as the main cooling strategy with the use an algorithm for the window operation as well as nigh cooling assuming 10% of the window operable area as ventilation area during the night time equivalent as almost 15% of the interior surface surpassing the 5% required by the normative. According to the SIA, there are two alternatives to comply with its requirements: [a] a performance-based method, in which a performance assessment is provided or [b] following a prescriptive method, in which the thermal properties of the building elements are specified directly from the code [7], The latter method is the most commonly followed by architectural practices, and therefore the one selected for this study. There are three sets of specifications to choose from when following the prescriptive method [3]. The first one is the maximum required U-value of the components of the building envelope for new buildings (mU), whilst the second one, is an optional improved set of lower U-values that are referred to as target values (cU), also for new buildings. The third option is the maximum U-value specified only for the refurbishment of existing buildings (eU). Table 2 presents a summary of these values. These three sets were configured and tested in the study model. Additionally, to discover the relationship between NV and overheating risk, two additional series of simulations were included, one considering a maximum Windows Effective Area (WEA) of 90%, and another one considering 50%, assuming that the most common window designs are sliding and pivot. Thus, 2 sets of simulations were executed, each set was composed of 3 groups corresponding to each set of specifications, and each group was composed of 96 simulations corresponding to each of the points in the grid.

Table 2. U-values of the building envelope components of the study model

	Target U-value (cU)	Maximum U-value (mU)	Refurbish U-value (eU)
Opaque Elements	0.10 W/m²K	0.17 W/m²K	0.25 W/m²K
Windows	1.00 W/m²K	1.00 W/m²K	0.80 W/m²K

2.3. Building performance: overheating and heating load

The local regulations [1,7] establish a calculation methodology that includes comfort bands and energy loads. The normative established two possible comfort formulas, one for free running buildings and another for heated, cooled and mechanical ventilated buildings, nevertheless it is unclear which one to use in a building with heating and mechanical ventilation and no active cooling. However, it is stated that the operative temperature range it is based on previous comfort studies [7]. The utilized comfort band is the one specified for heated and mechanically ventilated buildings with a comfort range from 22°C to 26.5°C for the summer months, with the heating setpoint, at 19°C. For the evaluation of overheating the standard establishes a limit of 400 hours above the upper comfort temperature as the maximum overheating occurrence. Considering this, the building performance was evaluated using heating load and the number of hours above 26.5°C as key performance indicators.

3. Results

The first set of results were obtained during a series of simulations performed to optimize the study model. During this process, the Window to Wall Ratio (WWR) was recognized as one of the most influential variables since it regulates and gives access to solar gains, and it is also a definite factor for the usable area for natural ventilation and therefore the passive cooling capacity of the building. Because of this, it was learnt that special attention shall be given to the window design since the effectiveness of ventilation depends on it, together with the functionality for different passive strategies scenarios such as night-cooling and cross-ventilation. The variation in the simulation results can be noticed at first sight, the change of the WEA did not affect the cooling load of the models, since the windows were automated depending on the internal air temperature. However, concerning the overheating hours, the WEA showed a great influence especially in locations at lower altitudes. The solar protection was also identified as one of the influential variables since it can significantly reduce the solar gains from the glazing areas, and therefore the overheating hours, a reduction of almost 50% of overheating hours were identified at locations below 1000 meters of altitude after applying the solar protections. In the initial cases where no solar protection was considered, most of the solar gains entered the building through the windows and the most overheated models were the ones with the lowest U vales (cU), after the application of the shading devices, the most overheated models were the ones with the higher U-values (eU) since the solar gains were greater due to the heat transfers through opaque materials.

During the first stage of the analysis of results, only the datasets with 90% of WEA were analysed as they were the ones with the higher percentage of time in comfort. The initial step was to compare the simulation results against the performance limits in the normative. Regarding heating load, the estimated load from the simulation was compared against the code's limit. It was observed that regulation targets were easy to achieve following the prescriptive thermal resistance values. In most cases these target values ($Q_{H,ta}$) were achieved with the initial model settings, and at the high altitude locations, it was still possible after a more elaborated fine-tuning of the model, including a different temperature for the window opening and deactivating the heating system during the warming hours of the day. For the case of the overheating hours, the number of hours above 26.5°C were verified against the established 400 hours limit, it was observed that the locations at the lower altitudes, with the highest yearly average temperature, were the most prone to overheating although, only in one of the cases the limit of 400 hours was surpassed. The relationship between the simulation results and the altitude of the locations can be appreciated in Figure 4, where is possible to perceive that the warmest locations present the lowest heating loads as well as the highest overheating hours, these locations are also encompassed at the regions of the Swiss Plateau and the South Side of the Alps.

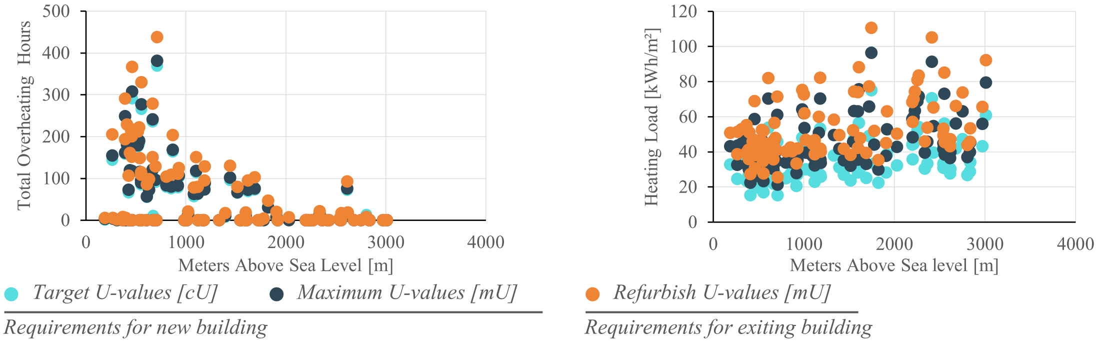

Figure 4. Simulation results grouped by altitude. The overheating results are presented on the left quantifying the total sum of yearly-hours above 26,5°C. The Heating load results are plotted on the right quantifying the yearly heating load in kWh/m².

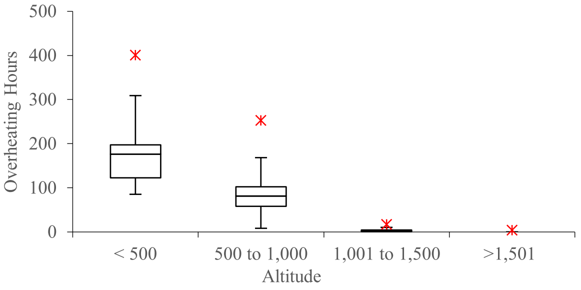

Figure 5. box plot of the average overheating values of each location.

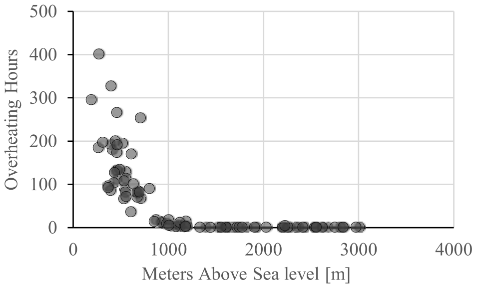

Figure 6. Average overheating values of each location and its altitude.

The second stage of the analysis focused on exploring the difference in performance between the simulations with a 90% of WEA and the ones with 50%. In the initial cases in which no shading devices were applied, the WEA had a great effect, it was showed as a generalized reduction of the overheating hours in all the cases that considered a 90% of WEA. Nevertheless, the results changed completely different in the final sets of simulations where the solar shading was applied, showing a minimal variation between the models. The average value of the all the overheating hours of every model, of each location were calculated and plotted as a box plot graph (Figure 5) in which it is possible to appreciate the difference in overheating across the different altitudes, these same values are presented in Figure 6. The simulations results revealed that the original objective of the normative regarding heating load is achieved. Additionally, it was revealed, that the application of shading devices can significantly prevent overheating and they can make up for a reduce WEA.

4. Conclusions

The study presented in this paper investigates the efficiency of the building Swiss normative in a CC scenario perspective, together with the limitations of natural ventilation as a solution for overheating in dwellings. For the investigation, weather data from 96 different locations were collected, and an archetype of the single-family building was simulated at these locations, simulations considering three different building envelopes performance in terms of U-values and two different values for Window Effective Area for natural ventilation as well as the application of external solar protection. Considering the results, it is interesting to see how the locations with the lowest altitude are the most prone to overheat and therefore the most affected by the CC phenomena, meanwhile, the locations at higher altitudes presented a minimal number of overheating risk hours and a decrease in the heating load as a consequence of CC, in light of this, the implementation of newer climate data can be beneficial to better predict the environmental performance of building energy models. Additionally, the integration of a more elaborate set of rules to prevent overheating risk in lower altitude settings can be a way of ensuring better-performing buildings in which the use of mobile solar protection becomes clearer and compulsory, together with natural ventilation and thermal mass.

The analysis suggest that the overheating suffered in most of the buildings nowadays can be prevented by the application of mobile shading devices since they can block a big part of the solar gains, additionally, the f_{cor} variable, used in the current regulation calculation method as a correction function, as well as the altitude and the yearly average temperatures may be useful in this process given that they contain indicative data of the conditions of a location. Further work needs to be done to establish the extent of these possible rules, nevertheless, they can be firstly explored by further investigating the actual effect of glazing ratio, and window's effective area, together with a more elaborated specification of the use of shading devices and the thermal mass of the wall's composition. Moreover, the recent effects of overheating in the population at the warmer locations, are indicators pointing towards the need for a better and more elaborated normative to establish the limits of overheating risk in domestic space in which the intensity and extent of overheating are better established and limited.

Acknowledgements

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