Chapter 12
Ventilative Cooling in Tertiary Buildings: A School Demo-Case and Parametric Analyses Under Swiss Climate Conditions (Central Europe)

Flourentzos Flourentzou

Abstract This chapter focusses on the description of a school nearly-zero energy building (Minergie® labelled), which was designed to include ventilative cooling strategies to guarantee summer comfort conditions. This building includes a gym, classrooms, and office facilities. The gym, 11 m in height, uses a cross ventilation strategy, exploiting the strong stack effect, while classrooms and office spaces use single-sided ventilation. This building acted as reference building for the International Energy Agency (IEA) research project Annex 62. A one-year monitoring campaign was conducted to calibrate the simulations performed with the software DIAL + to carry out a parametric analysis on main variables that are able to influence ventilative cooling performances. Although, this building does not include in its final configuration a dwelling-unit for the school keeper, the architect designed a fictive apartment within the building, to perform parametric simulations. In this chapter it is, in fact, also reported a parametric analysis covering the following building usages: school, office and residential. This analysis allows on the one side analysis of the main issues influencing ventilative cooling performances, and on the other side verification of ventilative cooling resilience under climate and microclimate changes, showing very good resilience to both climate changes and heat waves.

12.1 Chapter Structure

This chapter is divided into 3 main sections: the first—Sect. 12.2—describes a real demo-case and shows how to integrate ventilative cooling issues during a design process. It focusses on the challenge of opening architectural integration and dimensioning to assure thermal comfort; the second—Sect. 12.2—introduces a parametric study, based on a reference office room retrieved from the described demo case, to analyse the thermal behaviour of a space under ventilative cooling while varying the main design parameters; the third—Sect. 12.3—is a parametric study, based on the

F. Flourentzou (✉)
Estia SA, EPFL Innovation Parc, 1015 Lausanne, Switzerland
e-mail: flourentzou@estia.ch

G. Chiesa et al. (eds.), *Innovations in Ventilative Cooling*, PoliTO Springer Series,
https://doi.org/10.1007/978-3-030-72385-9_12

same office room, that analyses the impact of climatic and microclimatic conditions, with special regards to climate changes and heat waves.

Here below the main lessons learned by the three sections are reported.

12.1.1 Lessons Learnt—Ventilative Cooling Integration in Buildings

- Natural ventilation is an efficient and sufficient cooling strategy in the central European Climate.
- Without night ventilative cooling summer comfort is not sufficient in recent highly insulated buildings.
- Night natural ventilation is the one of the most important free-cooling techniques.
- Natural ventilation in spaces with a significant height (e.g. a gym) is easy to be designed. Stack effect is, in fact, very efficient and small opening areas (4–6 m^2) may generate several ventilative air changes per hour.
- In spaces characterised by a high height, positions and dimensioning of openings determine the neutral pressure level in the building, driving where the inducted airflows come in and go out from the building, and defining where cold air enters and where heat is evacuated. Neutral pressure level is a key phenomenon and need to be correctly managed to control summer and winter thermal comfort conditions and cold draughts in winter or freshness feeling in summer.
- Automatic natural ventilation may save significant amount of money and space replacing air handling units and ducts. Architectural elements, such as windows, light wells, and doors, may become functional elements of the automatic ventilation system.
- It is a good design technique, offering interesting solutions for the architectural language, the division between glazed openings devoted to natural light, which may remain closed, and ventilation openings that might be protected, automatized, or hidden.
- Natural ventilation has a key advantage over mechanical systems in addition to cost benefits: it may give solutions to the architectural language, avoiding ducts and large technical rooms.
- Simple dynamic simulation predictions of thermal comfort, taking into account air flow and temperature dependencies based on Bernoulli's equations, are sufficient to correctly design a ventilative cooling system. Simulation predictions result to be coherent with the real building behaviour.

12.1.2 Lessons Learnt—Parametric Study Varying Design Parameters

- Solar gains is the main factor to be controlled in order to provide summer thermal comfort. Even with very efficient solar protection, highly glazed façades present significant increase of cooling needs. Partial or incorrect control of blinds may also affect seriously thermal comfort. However, a well dimensioned and controlled ventilative cooling strategy may provide summer comfort without air-conditioning. However, ventilative cooling is not sufficient to provide comfort to a fully glazed room when 2-glazed façades are present (i.e. South and West or South and East).
- The level of internal gains affects summer thermal comfort and the efficiency of ventilative cooling. Swiss norms consider the level of thermal gains as a criterion to decide the need for air conditioning. Simulations show that internal gains are a bad criterion and are not sufficient to determine the necessity to install an air-conditioning system. With natural night ventilation we may admit up to 200–250 Wh/day instead of 140 Wh/day admitted by the norm. When internal gains are an issue, it is recommended to proceed with a dynamic simulation to determine the necessity for air conditioning.
- Window size, shape and positioning determine the natural ventilation airflow. A single simple indicator according to the % of openable façade or the m^2 of opening per m^2 of floor is not sufficient as design criterion.
- Mechanical ventilation rates higher than 2-times the hygienic-required ventilation consume a lot of energy and reduce the $SEER_{VC}$ (seasonal energy efficiency ratio of ventilative cooling) to unacceptable levels, lower than standard air conditioners. The number of operational hours for mechanical ventilation needs also to be optimised to reduce this number to the strict minimum requirement (<700 h) and operate the ventilation system for night cooling during the coldest hours of the night (generally between 00:00–6:00 a.m.).
- Thermal mass plays secondary role for medium to high thermal capacity rooms. However, for low thermal capacity buildings (e.g. wooden building), is sufficient to have a screed or one massive wall to provide sufficient efficiency of night ventilation.

12.1.3 Lessons Learnt—Climate Parametric Study

- Although surface temperatures of some urban metal or mineral surfaces may rise to high levels under solar radiation, the effect of the heat island concerning air temperature variations is more significant during night that during day. This temperature rise does not affect significantly internal temperature and comfort of well-designed buildings. Day and night ventilation still remain a sufficient passive cooling strategy ensuring comfort.

- The more intense and more frequent heat waves of the last years are the prelude of climatic changes. However, a well-designed building with the right solar control and the right day and night ventilative cooling remains comfortable even considering the worse climatic change scenario.
- A sufficient, practical and easy method to test the resilience of a building to climatic changes is to simulate its behaviour with the climate of summer 2003. Using the IPCC optimistic and pessimistic scenarios we found that event without a ventilative cooling strategy, the higher cooling needs are compensated with lower heating needs. Using an adequate ventilative cooling strategy the cooling needs are reduced practically to zero.
- The answer to climatic changes and to heat waves is not a generalised use of air conditioning in the Swiss and central European climate, but a generalised and well controlled ventilative cooling technique, with efficient solar and internal gain control.
- Overheating of building elements exposed to solar radiation (blinds, double skin of a facade, decorative elements, protections of vents) or obstructing the window opening (fabric solar protection, rain or security protections of vents) create more significant overheating problems than heat island effect and even heat waves.

12.2 The Saint-Germain Primary School in Savièse—A Ventilative Building Demo Case

12.2.1 Introduction

The “Commune de Savièse” organised an architectural contest to build a small 10-classroom school building with a gym. *rk studio* proposal won the first price of the competition, proposing a peculiar unified volume, as a response to the need to integrate a contemporary modern building in a traditional preserved Wallis mountain village on the Alps. The pure line of the form imposes several serious constrains on the design of a natural ventilation system. The building was firstly designed as a typical passive building, intended to get a Minergie® label, with two distinct dual flow ventilation systems, with heat recovery: one for the classrooms and one for the gym. The gym was designed as a fully-airtight mechanically ventilated volume, while classrooms had some windows that could be opened. From the outside, the building form is in relation with its alpine environment. This relation is maintained also inside the building, through the pure form of glazed openings, framing unique fragments of surrounding landscape (Fig. 12.1, 12.2, 12.3, 12.4, 12.5 and 12.6).

The architectural language of the chosen project was coherent with the initial airtight mechanically ventilated strategy. Windows did not have any functional use. However, very soon in the design phase, the high costs of technical installation became a limit to further project development, and the necessary ducts, to bring 6000 m^3/h of air in the gym space, necessary to also ventilate up to 200 childs in the

Fig. 12.1 The considered school-demo building, composed by two joint volumes. On the left part of the picture, it can be seen the gym volume, while, on the right side, there are the classrooms. The pure line of the building is part of the architectural language defined to draw the building at the macro scale, to guarantee the wished "monolithic" form and a dialogue with the surrounding alpine environment and traditional village shapes

school canteen, which is integrated to this space, was a cumbersome element, and contrasted to the building's pure line. Cost analysis of different solutions and architectural advantages, like duct integration and reduction in space-usages for machine installations, motivated the design team to choose purely natural ventilation for the gym and mechanical ventilation for classrooms and offices. The cost of the mechanical ventilation system was around 100'000 CHF, and the duct diameter was 2 × 75 cm for the fresh air and 2 × 75 cm for the exhaust channel. Natural ventilation does not represent any extra cost, because the 4 m^2 of necessary openings on the top and bottom of the space are also required by fire protection regulations, being related to smoke evacuation. The main challenge to apply natural ventilation strategies in the gym relates to define how to integrate large openings, necessary to create a stack effect of 6000 m^3/h, in the space without changing the architectural perception.

Fig. 12.2 The pure-line effect is a desired characteristic of the building and is maintained also in indoor spaces. For example, construction details offer pure openings to frame landscape from the inside, without window-frame obstructions

12.2.2 Window Position and Dimensioning of Air Path and Flow Rate of the Gym

During summer ventilation, fresh air enters from the basement as it is shown on Fig. 12.7 and leaves the building from the top openings as it is shown in Fig. 12.8. Summer ventilation is controlled according to inside and outside temperatures. When inside temperature is higher than 20 °C and outside temperature is smaller than inside temperature, bottom and top openings open. Ventilation stops when inside temperature falls below 18 °C or when there is heavy rain or strong winds. During winter, air enters from the lateral top openings, which are positioned 2 m lower than the top front opening. The fact to make the air entering from openings situated 6 m above the floor allows the cold air to mix before reaching the occupants and to avoid cold draughts. When CO_2 concentration rise over 1000 ppm, top openings open 10%. Openings are closed when CO_2 levels fall below 600 ppm (Fig. 12.9).

Natural ventilation airflow was simulated using DIAL + software [1] to correctly dimension the openings in order to guarantee enough night ventilation for free cooling the building [2]. The position of the openings is intended. The bottom opening position in the storing room activates the concrete thermal mass of this extra space and stores coolness during night. It also avoids cold draughts because event in summer

Fig. 12.3 The assumed design solution, able to respect architect's requirements for pure glazed openings, was to dissociate air paths from light paths. The picture shows an opaque opening on the top of the space, which guarantees the evacuation of hot air from the top and avoid the creation of a hot buffer space under the roof triangles. Glazing systems on the bottom offer only light and view, without being included in the natural ventilation solution

Fig. 12.4 On the left picture, it is possible to see the building as it was on the architectural contest poster. On the right as it was realised. The only difference is the opaque windows that can be only be guessed—see for example the top of each triangular roof of the gym and the vertical façade on the right picture

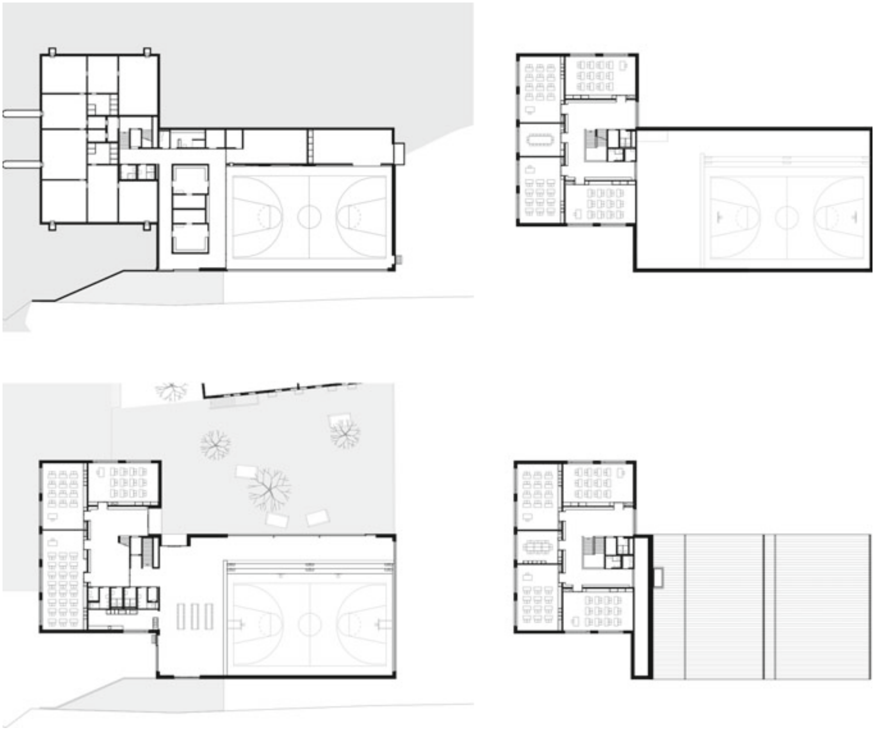


Fig. 12.5 Plans of the reference building

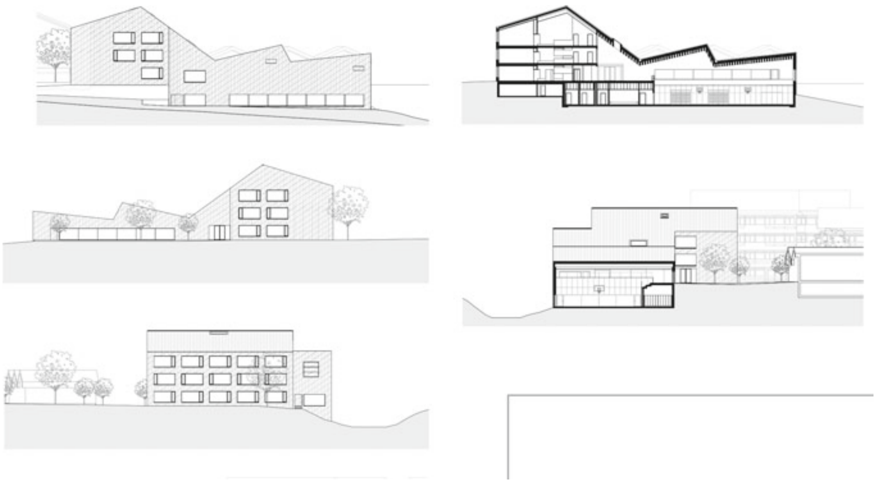


Fig. 12.6 Facades and cross sections of the reference building

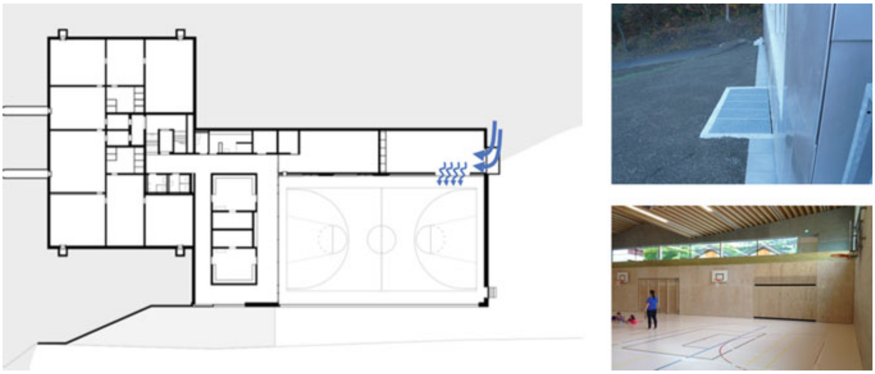


Fig. 12.7 A bottom 4 m^2 opening brings fresh air from a basement light-well situated in the storing room. Air enters through two automatic windows and passes through the perforated door that can be seen on the bottom right picture

Fig. 12.8 A top opening of 6 m^2 evacuates air on the top of the canteen (right picture) and two additional 1 m^2 openings (left drawing) allow a better distribution of air evacuation when the basement opening is open. This figure shows the night ventilation summer strategy with fresh air entering by the basement and being exhausted from the top openings

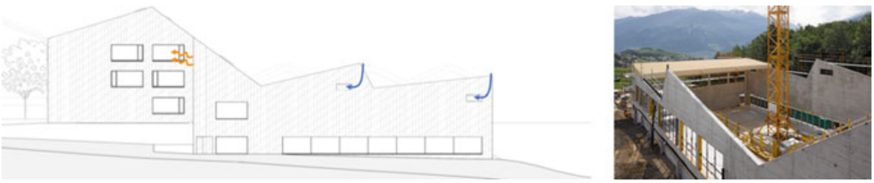


Fig. 12.9 Winter natural ventilation strategy: the basement opening is closed, and the air enters from the top lateral openings situated lower than the big 4 m^2 opening shown in Fig. 12.8. Cold air enters at 8 m in height, is mixed with hot air until it falls to the floor to avoid cold draughts. Users have not reported any cold draughts in the first-year of usage of the gym

there are fresh days that might create cold draughts. The passage of the air through a perforated wooden door was designed to create a laminar and well distributed airflow. The positioning of the automatic window in the storing room prevents children to play with it. Extra protection grids are defined to prevent children to access the automatic openings from inside, and from outside to protect from rain. Top openings prevent the creation of hot air buffer zones in the roof triangles. The big exhaust opening position on the opposite side of the air inlet assures swiping the whole space with fresh air. It is positioned on the top of the canteen space to allow the direct evacuation of pollution where the higher human concentration takes place (Figs. 12.10 and 12.11).

As it is shown in Fig. 12.10, the control of the neutral level is essential to elaborate a ventilation strategy, because it determines where fresh air enters and where exhausted air is evacuated from the building. The DIAL + images illustrate how, in summer, the main mass of inlet air enters from the bottom opening while during

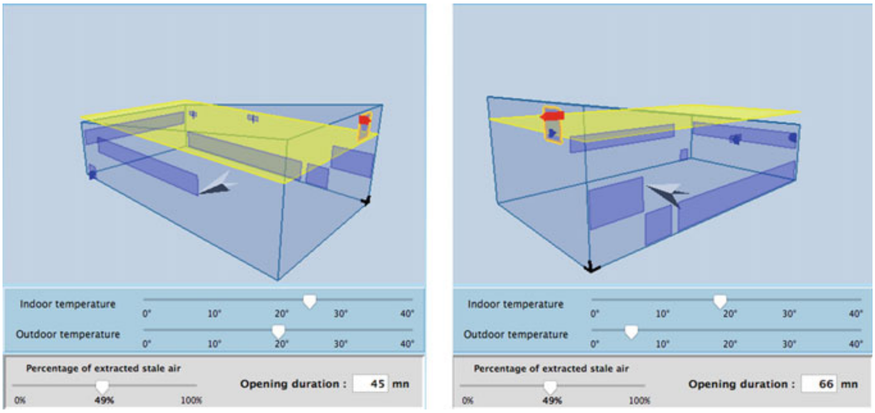


Fig. 12.10 DIAL + simulations to dimension window openings. On the left image, we can see summer ventilation with 7278 m^3/h entering from the bottom opening and 2 lower top openings under the neutral level calculated to be at 9.34 m in height when $\Delta T_{in\text{-}out}$ is 5 °C. On the right picture, we can see winter ventilation strategy. In this case the neutral level is in the middle of the top opening at 10.4 m while the airflows are 2094 m^3/h of exhaust air and 422 m^3/h of inlet air from the same opening and 1077 m^3/h + 1406 m^3/h of inlet air from the lateral top openings under the neutral level

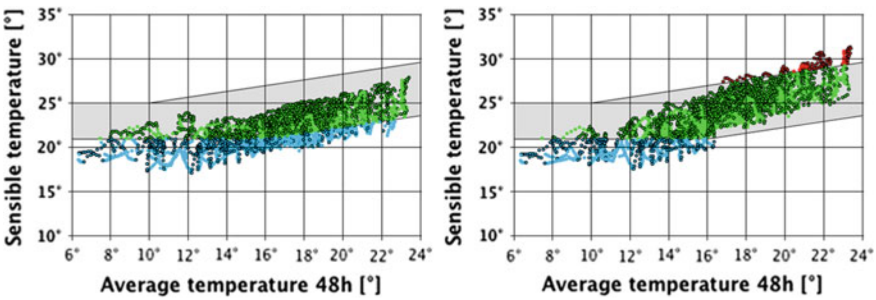


Fig. 12.11 DIAL + dynamic simulations for summer comfort. The left image shows the building behaviour with good solar control and night ventilation, remaining 2–3 °C under the upper comfort limit defined in the EN 15251 standard. The right graph shows a building configuration in which ventilation occurs only during working hours and there isn't a solar control system: the building does not comply with the comfort conditions defined in the same standard

winter it enters from the 3 top openings. By fixing the in and out temperatures in the software, it is possible to calculate the orders of magnitudes of the airflow rate. Nevertheless, detailed dynamic simulations with a coupled air/heat model need also to be used to determine if the airflow rate is enough to guarantee comfort levels, especially for the cooling strategy. The first defined strategy did not include solar control and night ventilation strategy. The adoption of dynamic simulations—see results in Fig. 12.11—showed that night ventilation and solar control are essential to guarantee building comfort conditions.

12.2.3 Window Position and Dimensioning for the Classrooms and Offices

The majority of the classrooms are West oriented. Large glazed areas (4X2 m) structure the façade rhythm. On the side of each fixed-glazed area, an openable window (0.6X2 m) enables sufficient natural ventilation during summer. For security reasons, in order to have 1 m height underside of the window, a 40 cm glazed protection was included. This protection reduces the effective opening to 0.6×1.6 m. A dual flow ventilation with heat recovery offers a ventilation rate of 5.2 m^3/m^2h according to design standards for classrooms. Night ventilation may be performed through natural or mechanical ventilation systems. The office spaces are similar to classrooms with smaller dimensions. A classroom benefits of two windows while an office room has only one window. The reference room, which was assumed for IEA Annex 62 project, is the office room in the middle of the building (indicated in yellow on the drawings below).

Outside automatic venetian blinds offer a perfect solar protection to the building according to the Swiss standards (g value <0.1). All the building concrete surfaces offer an exposed thermal mass except of the ceiling. Floors are concrete slabs with screed covered with a thin parquet flooring. Ceilings are made in exposed concrete, but a suspended ceiling hides thermal mass and avoid thermal mass activation. However, simulations in the design phase showed that the exposed thermal mass of concrete walls and floors is sufficient to reach summer comfort (Fig. 12.11).

An office room was chosen as a reference room for analyses, considering its size and position in respect to the building. It size is similar to the control room defined in the EN 13590 standard, which makes it easier to check the validity of the results and calibrate the model. The simplicity of the construction with exposed concrete walls inside and insulation outside, the shape and size of the openings, and the presence of efficient and well-managed venetian blinds make this space an ideal room to act as a reference building-space for parametric analyses.

The chosen building space was monitored during the 2015 school holidays when the school was unoccupied. It was equipped with sensors to measure air and surface temperatures on both sides of each wall, a camera that recorded the position of the blinds and window, and electric lamps that simulated internal gains according to SIA

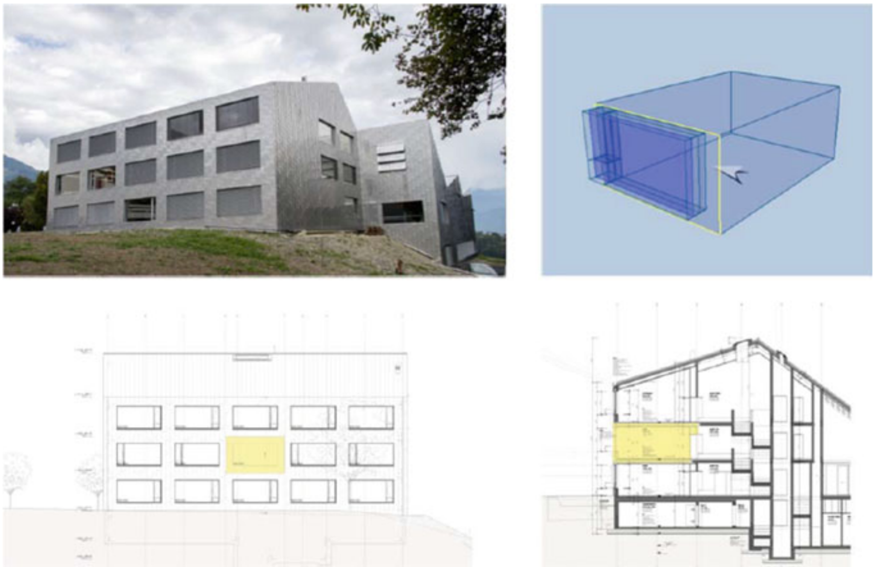


Fig. 12.12 Saint-Germain primary school in Savièse [30]. The yellow space is the one used as a reference to be modelled and monitored in order to allow a comparison between predicted and real performances

2024 technical specifications [3]. Four dynamic simulation software were used and showed coherent results with measures (EnergyPlus, LesoSai, SIA TechTool, and Dial + [1]). We used Dial + to produce the results of the parametric study.

12.3 Parametric Study Setting Ventilative Cooling Under Design Choice Variations

This section analyses the thermal behaviour of the same office room defined above by varying the main design parameters. The parametric analysis calculates comfort and energy key performance indicators for each design parameter variation in order to quantify its influence. Profiting by the calibration of dynamic simulation parameters with real measurements on the Swiss case study, we used the calibrated DIAL + to simulate the reference office, varying solar gains, internal gains, ventilation rate through the variation of the window size or position and the mechanical airflow rate and evaluate the effect of variation on comfort and energy indicators.

Hence, with a consolidated set of comfort and energy indicators [4, 5], a reference building and robust and validated dynamic simulation software, it is possible to perform a parametric analysis of ventilative cooling performances and compare them with other cooling strategies, including air conditioning.

The aim of this analysis is to use the results of Annex 62 focussing on a sample climatic and normative background—the Swiss one—to answer two questions:

– Is it possible to completely avoid mechanical air conditioning by using a ventilative cooling strategy?
– If so, what are the influencing factors, risks and limitations of this strategy?

The adopted methodology consists in taking standard conditions for 3 different uses according to SIA 2024 technical documentation [3]. Applying the thermal characteristics and ventilative cooling strategies of the reference building, we vary the influencing factors and evaluate the performance indicators. The tested ventilative cooling strategies are listed here below:

– $\mathbf{V_0}$ Standard conditions SIA 2024 without cooling ventilation
– $\mathbf{V_d}$ Optimum window opening during use ($T_e < T_i$ and $T_i > 26$ °C)
– $\mathbf{V_n}$ Optimum window opening day and night ($T_e < T_i$ and $T_i > 26$ °C)
– $\mathbf{V_m}$ Mechanical night ventilation (2.6 m^3/m^2h when $T_i > T_e + 2$ °C)

The same thermal characteristics described in the Table 12.1 are assumed, while the simulated dimensions of the rooms are those of the standard SIA 2024 rooms A office: 6.00 × 6.00, B classroom: 10.00 × 8.00 and C housing room: 5.00 × 5.00. Real dimensions of rooms are slightly different (5.00 × 7.00 for A and 10 × 7:00 for B) but we choose the standard characteristics (giving practically the same results) in order to make the results comparable to the reference indicative values (Table 12.2).

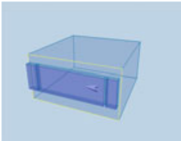
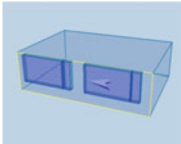
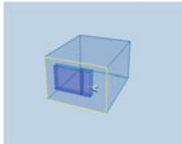
Each window measures 4.00 × 2.00 m with an opening part of 0.6 × 1.60 m for office and school use, giving an air flow rate $q_{\Delta T5°} = 337$ m^3/h per opening. For residential use, the window is adapted to 0.6 × 1.3 m in order to correspond to the standard room glazing window-to-wall ratio of 30% with an air flow rate $q_{\Delta T5°} = 247$ m^3/h.

The daily internal gains under standard SIA 2024 conditions are 153 Wh/m^2 for offices, 266 Wh/m^2 for school rooms and 96 Wh/m^2 for housing. The Swiss norm SIA 382/1 [6] concerning ventilation and air conditioning defines the necessity for

Table 12.1 Thermal characteristics and standard building conditions

Exterior wall	U 0.2, concrete wall, external insulation	Terms and conditions of use	According to SIA 2024
Interior walls	U 2.9, exposed concrete	Hygienic ventilation rate	2.6 m^3/m^2h (SIA 2024 time schedule)
Windows	Uf 1.3, Uw 0.6 opening 0.6 X 1.2	Opening the windows	Window opening if $T_i > T_e > 26$ °C
Interior door	U 1.2	Night ventilation	If $T_i >$ Te + 2 °C and $T_e > 21$ °C
Floor-ceiling	U 0.32 False ceiling, concrete, glued parquet	Mechanical night ventilation	5.2 m^3/m^2h 24:00 to 6:00
Blinds	Automatic slat blinds g 0.1	Blinds control	Automatic if $T_i > 22$ °C and I > 200 W/m^2

Table 12.2 Standard analysed rooms for office, classroom and housing rooms

	A. Office	B. Classroom	C. Housing
			
Dimensions	6 × 6	10 × 7	4 × 5
Glazing	50%	50%	30%
Openings	2 openings 0.6 × 1.6	2 openings 0.6 × 2	0.6 × 1.3
*$q_{\Delta T5°C}$ [$m^3/m^2/h$]	18.7	9.6	12.3
Thermal capacity	Average	Average	High
Int. gains. [Wh/m^2]	153	266	96

* $q_{\Delta T5°C}$ [$m^3/m^2/h$] is the natural ventilation flow rate when temperature difference between in and out is 5°C

air conditioning according to internal gains. Application of this simple indicator privileges air conditioning. However, in Switzerland there is another norm, determining the comfort requirements, SIA 180 [7]. This norm proposes to verify the necessity of air conditioning with dynamic simulation and takes into account night ventilative cooling. According to this norm, no air conditioning is necessary in all analysed rooms. According to [8, 9] in the majority of national regulations in Europe, night ventilative cooling is not considered. Determining the necessity for air conditioning only according to thermal gains, it does not take into account the capacity of the building to evacuate passively these gains.

As underlined in the design guide of Annex 62 [4], by performing a sensitivity analysis of parameters influencing ventilative cooling, the first parameter influencing thermal comfort is solar gains, followed by internal gains and the degree of window opening. For windy regions, whereas Switzerland isn't, wind is also an important influencing parameter. However, parameters such as the U-value of walls and roof, defined in comply with current legal requirements, do not play a role of the same importance. Based on this study, we have chosen the parameters to be modified under the Swiss weather and standard conditions of use. Before varying the parameters, we calculated indicators for the 3 most common building uses—see Sect. 12.3.1. Furthermore, as mentioned before, solar gains can be significant because of poor solar design but also because of very high window-to-wall ratio (WWR) or because of inappropriate use by the occupants in not automated spaces. These parameters are simulated to evaluate comfort and energy indicators. Three simulation cases will vary de window-to-wall ratio:

– The standard office with WWR = 50%;
– A fully glazed façade from ceiling to floor—WWR = 84%;
– Two bully glazed façades of an angular office

We will also consider a poor use of the blinds with only 50% of activation under standard office conditions with WWR = 60%. See Sects. 12.3.2 and 12.3.3.

Internal gains can also vary and this index is the second influencing factor influencing thermal comfort. In the technical documentation SIA 2024, 3 levels of internal gains and occupation levels are underlined and the same are here simulated. In this case, the degree of window opening can be a critical issue, such as mentioned before in the chapter. Therefore, in this analysis, the degree of window opening is also varied—see Sects. 12.3.4 and 12.3.5.

The last considered parameter is the thermal mass that is here analysed more in detail. We evaluated, in fact, the influence of this specific factor in collaboration with the Smart Living Lab of the EPFL where we built an experimental device with two standard rooms characterised by different thermal masses. We experimentally tested the rooms with light and medium thermal mass using earth walls or floors as mass elements. A combination of factors can create extreme situations. For example, a light room with too much glazing and a low degree of opening can lead to situations of severe overheating. Another critical combination might be low thermal mass on a building with too much glass. In this combination, thermal mass plays a different role than on a moderately glazed building where its influence is less critical. This analysis can be important for the design of wooden buildings especially with high degree of glazing—see Sect. 12.3.6.

The simulations were carried out with the DIAL + software.

12.3.1 Comfort Indicators and CRRs for Office, School Living Room Uses

The first parametric test shortly analyses the effect of different building usages of the reference standard rooms described in previous sub-sections. Firstly, the number of overheating hours according to EN 13521 standard are calculated for cases above, additionally the Cooling Reduction Ratio (CRR) is calculated—see the following expression. Results are reported in Table 12.3.

$$CRR = 1 - \frac{Q_c^{scenario}}{Q_c^{ref.}}$$

where the cooling energy needs for the ventilative cooling scenario are compared to the cooling needs for the reference fully-mechanically cooled case.

Table 12.3 Overheating hours and CRRs for the main natural ventilation strategies

	A office	B school	C housing
Default cooling requirements SIA 2024	10.8	16.9	6.5
DIAL + standard cooling requirements	9.9	11.8	6.4
Overheating hours * V_0	902	738	1909
Overheating hours* V_d	40	214	0
Overheating hours * V_n	0	34	0
CRR V_d	0.73	0.41	0.98
CRR V_n	0.92	0.69	1.00

*Overheating hours according to EN 13521 standard

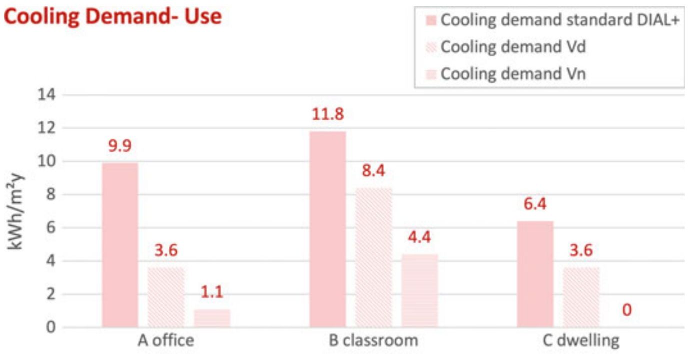


Fig. 12.13 Cooling requirements of 3 ventilation strategies for office, school, and residential building uses

As can be seen above, without opening the windows (V_0) there are between 738 and 1909 h outside of the comfort zone during the hours of use (for the dwelling case there are many more hours of occupancy) (Table 12.3).

The daytime opening strategy (V_d) drastically reduces the hours of discomfort, day and night ventilation strategy (V_n) removes almost every hour of discomfort—except for school room, where the number of people is larger and the operating temperature is at the limit of the comfort zone with few hours of discomfort (i.e. 34).

The reduction in cooling requirements is also very significant, since night ventilation eliminates practically any cooling requirements except for the school room. In addition to greater internal gains, the size of the openings (2 openings of 0.6 m × 1.6 m) is smaller. Some of the teachers in the school have made this remark (i.e. lack of air when it is hot). For this reason, one of the parameters that we are going to vary later on is the size and number of windows.

As can be seen in the graph, for the collective housing use it is sufficient to open the window and comfort is ensured.

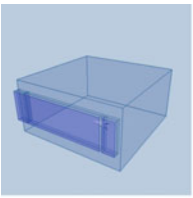
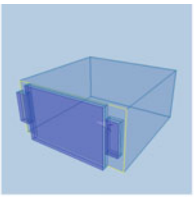
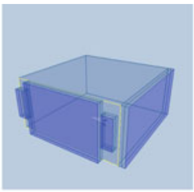
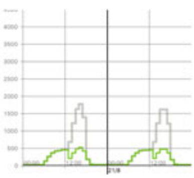
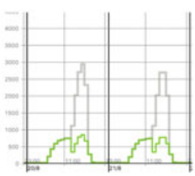
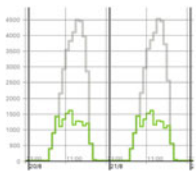
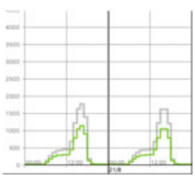
Influence of the use (school, office, residential)
• The thermal behaviour of the rooms is highly dependent on the use of the building.
• For all uses, a suitable ventilation strategy makes air conditioning superfluous.
• If day and night ventilation is not possible, daytime ventilation greatly reduces the need for cooling.

12.3.2 Impact of the Solar Gains (Glazed Ratio and Efficiency of Blind Management)

We have simulated the standard office SIA 2024 once with a 50% glass ratio, once fully glazed with a glass ratio of 84%, and once with two glazed façades of an angle office with 84% and 100% glass ratio. Finally, we tested the first case, 50% glazed room, with a poor blind management strategy (the blinds are half closed).

The analysis of solar gains reported in the Table 12.4 already gives to the reader interesting information that will be further expanded with a thermal behaviour analysis of the room. The room with an under-window wall reaches 500 W (14 W/m^2) in the afternoon with the blinds down. The same order of magnitude is reached in the morning with diffuse radiation gains (the window is facing west). From 1 p.m. the blinds are lowered, being blinds automatic activated as soon as the incident solar radiation exceeds 200 W/m^2. The properties of external blind solar protection used in this analysis based on technical specification 2024, with a g = 0.14 (protection + glazing) and triple glazing of g = 0.5. In the second case with a higher WWR,

Table 12.4 Glazed areas and solar gains for the scenarios simulated on 20 and 21 August

			
			
Standard awnings	1 glass façade	2 glass façades	Blinds 50%.
50% glass	Glazed 84	84/100% glass	50% glass

solar gains rise to 750 W (21 W/m^2), and with two glazed façades the gains rise to over 1500 W (42 W/m^2). With partial manual use of solar protection, which is very common in offices [10, 11], in the afternoon we have more than 1000 W (28 W/m^2) instead of 500 with the blinds closed.

As can be seen in the Table 12.5 and Fig. 12.14, solar gains are a major factor, both for thermal comfort and energy consumption for air conditioning, or the efficiency of the ventilation cooling strategy. Heat requirements rise from 9.9 kWh/m2 to 13.7 kWh/m^2 (138%) with a WWR = 84% and to 22.5 kWh/m^2 (225%) with a corner office with two glazed façades. Partial use of the blinds increases the cooling

Table 12.5 Comfort and energy indicators for 4 solar gain scenarios

	Reference Glass ratio 50%	Glazed on 1 facade 84%	Glazed on 2 façades 84/100%	Reference 50% blind closed
Hours of overheating* V_0	902	1010	1293	960
Overheating hours* V_d	40	107	591	70
Hours of overheating* V_n	0	4	367	0
Hours of overheating* V_m $q_{SIA} \times 1$	177	460	1043	298
DIAL + standard cooling requirements	9.9	13.7	22.5	11.9
CRR V_d	0.73	0.66	0.52	0.69
CRR V_n	0.92	0.85	0.68	0.89
CRR V_m $q_{SIA2024} \times 2$	0.78	0.66	0.42	0.73

*Overheating hours according to EN 13521 standard

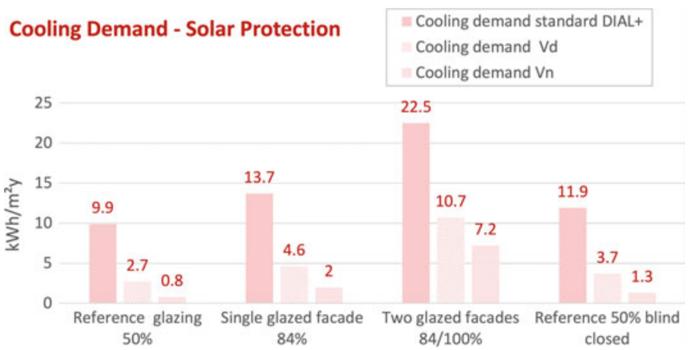


Fig. 12.14 Cooling requirements for 4 solar gain scenarios

requirements to 11.9 kWh/m^2 (120%). In terms of the effectiveness of the ventilation strategy to cool the mentioned spaces, the impact is very significant for the single 84% - glazed façade and catastrophic for the case with two - 84% glazed façades. With daytime ventilation only, comfort is clearly not guaranteed and the number of overheating hours is respectively for the two cases 107 and 591. Night ventilation barely guarantees comfort in the single 84% - glazed façade case, but shows 367 h of overheating in the two 84% - glazed facades' condition. A fully glazed office building, especially for corner spaces, would therefore be compulsorily air-conditioned in order to meet the comfort requirements. This is the only situation in where we found that night cooling is insufficient to provide summer comfort.

A corner room with two glazed façades, it is not only influenced by the mentioned solar gains thermal loads from windows, but it also has a radiative load. Both glazed façades, even with a good solar protection, show a surface temperature ranging between 27 to 28 °C instead of the 26 °C in case we had plein walls. To compensate the effect due to the warm radiation feeling, users often set the air conditioning to 24 °C (even to 22 °C) instead of the recommended standard 26 °C. This lower set temperature generates additional energy consumption.

As can be seen in the graph (Fig. 12.15), lowering the setpoint to 24 °C has disastrous effects on the energy consumption of the building. The cooling requirement for a glazed office is double in respect to the normal situation (19.7 kWh/m^2) and for the corner office is more than triple (31.9 kWh/m^2). Cooling needs exceed heating needs, and if there are no local free cooling sources (e.g. lake water), the same building will never reach a high or very high energy standard. Nor can we rely on night ventilation to drastically reduce energy consumption. As can be seen in the Table 12.4, the CRR of the over-glazed office with night ventilation is 0.68 instead of 0.92. With a setpoint of 24 °C the CRR is even lower (0.45). Additionally, the implementation of a hybrid system with air-conditioning and natural ventilation of a room with such needs becomes difficult to achieve and regulate.

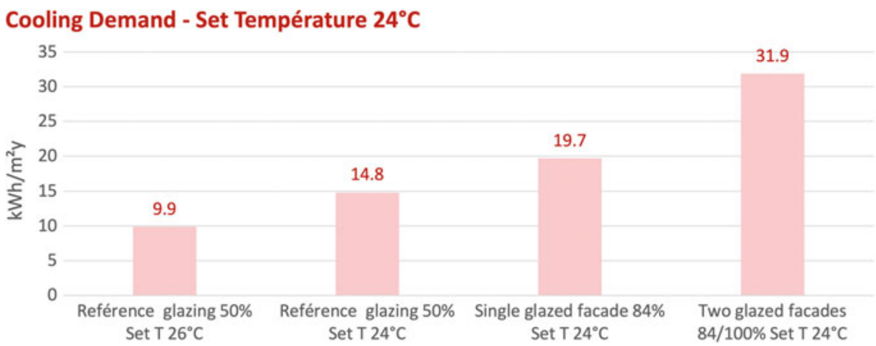


Fig. 12.15 Cooling requirements with a setpoint of 24 °C

12.3.3 Solar Gains: East and West Orientations

We have simulated the behaviour of the same rooms facing east and west. In the presence of well-regulated sun protection, the two orientations behave in the same way. While one orientation is exposed to direct solar gains that pass through the blind, the other orientation receives diffuse radiation without moderation by solar protection. The order of magnitude of the diffuse solar gains without solar protection and the direct solar gains moderated by the blind is the same—see simulation results reported in Table 12.3.

Nevertheless, a difference between the two orientations becomes significant when there is insufficient or no sun protection. This can happen in several contexts, such as when:

- buildings are old with interior solar protection,
- the solar protection control is manual, and the users lower them only partially,
- the blinds' colour is dark and they preheat the incoming air a lot in the presence of direct radiation.

We have simulated these cases with a generic simulation that takes 50% of the direct and diffuse radiation passing through solar protection. The differences in terms of annual indicators are small. However, there are days where ventilation is more effective in the east-oriented room in respect to the west-oriented case. During mooring, cool exterior air removes more efficiently morning solar gains. In the west, solar gains come when air is already too hot to remove them efficiently through natural ventilation (Fig. 12.16).

In terms of annual indicators, considering the above-mentioned strategy of solar protection having 50% of the blinds lowered, we have 11.4 kWh/m^2 of heat requirements for the east orientation instead of 11.9 kWh/m^2 for the west orientation. The CRR for daytime ventilation is 0.71 for east orientation instead of 0.69 for west orientation and the CRR for night ventilation is 0.91 for east orientation instead of 0.89 for west orientation. We have also simulated the southern orientation. With strict or automatic sun protection, thermal behaviour is similar for all orientations. With deficient protection (50% of blinds lowered), south orientation is slightly more penalised than east or west, as it is exposed to sun radiation for a longer period of time.

Influence of the glazing and sun protection
• The simulations confirm the major influence of the glazed part of the room and the management of solar gains, for summer thermal comfort and the efficiency of the ventilation strategy.
• A room with a fully glazed façade on a single side is warmer and consumes more energy for cooling. The daytime ventilation strategy is not sufficient to provide comfort, but the night-time ventilation strategy barely manages to provide it.
• A corner room with two glass facades (south and west) consumes much more energy and must be individually dimensioned for power and cooling distribution. No ventilation strategy, day or night, is sufficient to ensure summer comfort for such a room.

(continued)

(continued)

Influence of the glazing and sun protection
• Automation of blinds, which is compulsory in the case of air-conditioned building in Switzerland, is also desirable for naturally cooled rooms, especially if they are too much glazed. Overheating hours are much higher with poor blind control.
• The orientation of the room to the south, east or west does not influence the energy performance if the blinds are rigorously managed. With less strict blind control, east orientation is slightly preferable, because the cooler morning air removes more efficiently the excess heat.
• An over-glazed façade has a negative influence on thermal comfort and energy consumption for cooling in the same degree as climate change and heat waves.

12.3.4 Effect of Internal Gains

The Swiss norm SIA 382/1 states that from 140 Wh/m^2.day to 200 Wh/m^2.day, even with day and night ventilation, air conditioning is desirable, and with over 200 Wh/m^2.day it is necessary.

All simulations carried out adopt standard conditions of use defined in SIA 2024 totalising internal gains of 153 Wh/m^2.day. We have seen in the previous sections that with these conditions of use night ventilative cooling can provide comfort even for an 84% glazed room and can guarantee the comfort of the reference room even with global warming in 2060—see the following Sect. 12.4. In this paragraph we have doubled the occupancy and the heat emission of the appliances according to SIA 2024, which leads us to put 5 people in 36 m^2 (10 W/m^2), 540 W of heat by the appliances (15 W/m^2) and 572 W of gains for lighting (15.9 W/m^2). With these changes gains rise to 256 Wh/m^2.day, much higher than the limit of 200 Wh/m^2.day that SIA 382/1 sets for air conditioning rooms that may have night ventilation. The results in the following Table 12.6 show that even with 256 Wh/m^2.day of internal gains we manage to cool the reference room with night and daytime ventilation and guarantee summer comfort.

If we analyse the graph in the Fig. 12.17 we can see that doubling the occupancy/heat release increases the cooling requirements by 52%, reaching 15.2 kWh/m^2. With more internal gains, a daytime ventilation strategy evacuates more heat in absolute value (9.5 kWh/m^2 instead of 7.2 kWh/m^2 with the gains of the standard conditions) but in relative value, its CRR cooling capacity is 0.63 instead of 0.73 and the remaining hours with temperature out of the comfort zone increase to 112 h instead of 40 of the standard conditions. We have the same phenomenon with the night ventilation strategy, where although it evacuates 12.6 kWh/m^2 the CRR drops to 0.83 with 4 h outside the comfort zone. In the Table 12.6 we have produced the comfort diagram according to EN 13251 and we can see that for the reference room the points approach the upwards limit of the comfort zone, whereas with the standard gains the point cloud is much lower than the same upper comfort line.

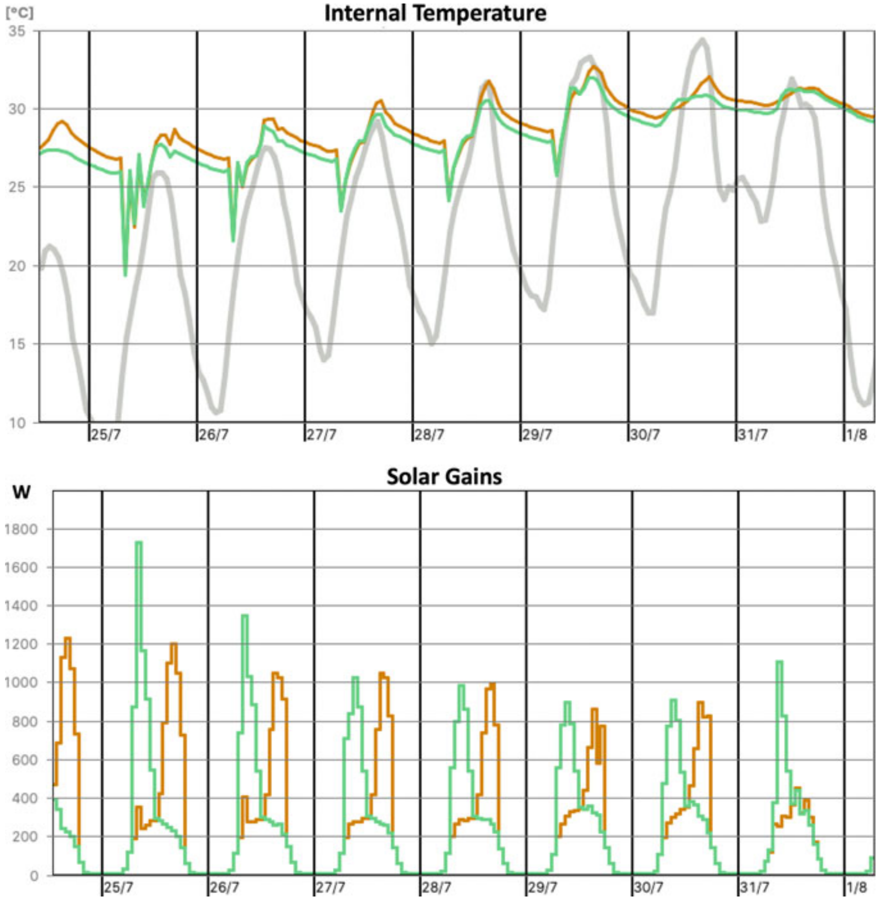
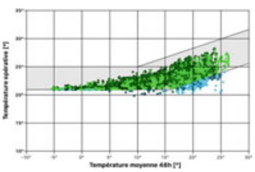
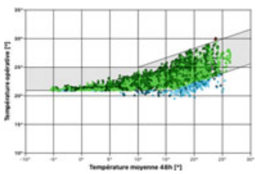


Fig. 12.16 Solar gains and indoor temperature for the reference room facing east (green) and west (red) during a hot August week

We have reproduced the table of the SIA 382/1 standard for the 50% glazed reference room with 1 m^2 of opening surface. According to the official norm, it is necessary to install air conditioning because this approach strongly underestimates the cooling potential of a night ventilation strategy, whereas it overestimate the potential of ventilation through windows during occupancy that could provide comfort with up to 140 Wh/m^2.day internal gains. It overestimates also mechanical ventilation potential providing comfort with up to 120 Wh/m^2.day internal gains. According to our simulations, in order to have zero hours of discomfort whether with a strategy of opening windows during occupation, or 24-h mechanical ventilation without opening windows, internal gains must be reduced down to 90 Wh/m^2.day. To move away from the limit of discomfort defined by the EN 13251 diagram, the internal gains must be further reduced to 70 Wh/m^2.day. These values can of course be higher with a lower

Table 12.6 Simulation results for the reference room (153 Wh/m^2.day of internal gains) and the same room with double occupancy (256 Wh/m^2.day of internal gains)

	Standard earnings—153 Wh/m^2 day	Double occupancy—256 Wh/m^2 day
Hours of overheating V_0	902	1242
Overheating hours V_d	40	112
Hours of overheating V_n	0	3
Hours of overheating V_m $q_{SIA} \times 1$	177	735
Comfort diagram V_n		
DIAL + standard cooling req.	9.9	15.1
CRR V_d	0.73	0.63
CRR V_n	0.92	0.83
CRR V_m $q_{SIA2024} \times 2$	0.78	0.58

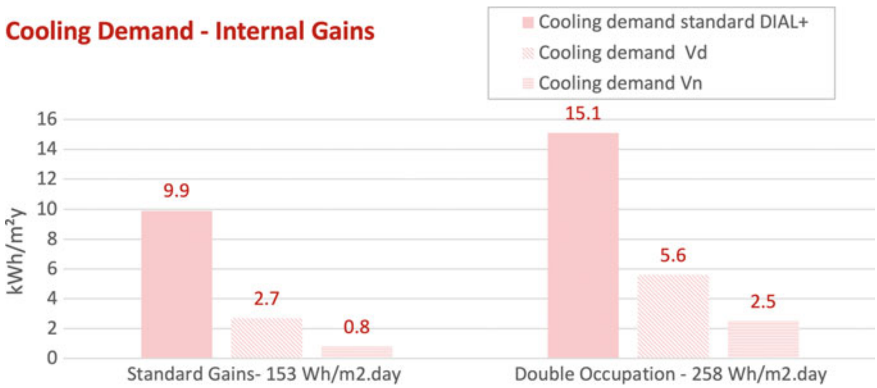
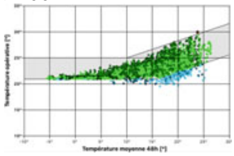
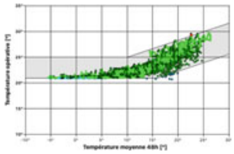
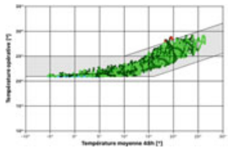
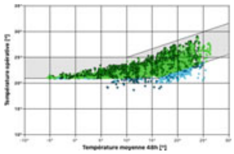
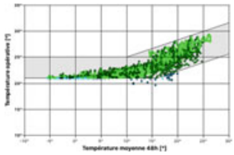
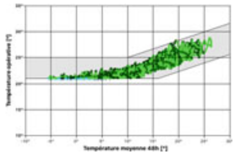


Fig. 12.17 Cooling requirements with standard occupancy according to SIA 2024 (153 Wh/m^2.day) and with double occupancy (256 Wh/m^2.day)

Table 12.7 Table from SIA 382/1 with proposed alternative limit values determining the air-conditioning requirement

	Internal thermal input Wh/m^2.day		
	Window ventilation day AND night	Window ventilation during hours of use	Without window ventilation*
Necessary	>250 >200 	>90 >140 	>90 >120 
Desirable	200–250 140–200	70–90 100–140	70–90 80–120
Superflux	<200 <140 	<70 <100 	<70 <80 

*Overheating hours according to EN 13521 standard

WWR, with presence of cross ventilation (not taken into account in these simulations), or with the use of more efficient blinds (the g = 0.38 considered in standard conditions corresponds to movable blinds positioned at an angle of 45 °C). We can retain that with internal gains higher 70 Wh/m^2.day we have to verify the comfort with a dynamic simulation.

It can be stated that, with night ventilation, the reference room can absorb up to 200 Wh/m^2.day, a value much higher than the 140 Wh/m^2.day indicated in the SIA 382/1 standard (Table 12.7).

The value of 153 Wh/m^2.day corresponds to the standard occupancy of the reference room—2.6 people for 36 m^2, internal gains of 7 W/m^2 (252 W) and 15.9 W/m^2 for lighting (572 W) with a daylight autonomy of 50%. The value of 90 Wh/m^2.day corresponds to a standard occupancy with low internal gains (3 W/m^2) and a daylight autonomy of 65%, while the value of 70 Wh/m^2.day corresponds to an occupancy of 1 person per 36 m^2, low internal gains (3 W/m^2), low consumption lighting (12 W/m^2 with 65% daylight autonomy).

Influence of internal gains
• Internal gains play an important role for summer comfort and the effectiveness of the ventilation cooling strategy, as much as solar gains.

(continued)

(continued)

Influence of internal gains
• All measures must be taken to reduce internal gains before counting to the cooling strategy: choice of appliances, occupancy density, well-dimensioned lighting with very low consumption and regulated “manual on—auto off”, maximisation of daylight autonomy.
• The SIA 382/1 Swiss standard underestimates the efficiency of night ventilation and overestimates the efficiency of ventilation during occupation, whether natural or mechanical. Instead, the criteria of SIA 180 should be used to determine the need for air conditioning and be verified by dynamic simulation.
• Internal gains are not a good indicator to determine the necessity of installation of mechanical air-conditioning. A dynamic simulation taking into account the real effect of the other parameters and especially night ventilation potential is the right method.

12.3.5 *Effect of Ventilation Rate*

According to the design guidelines in IEA Annex 62 [4] after solar and internal gains, the factor that most influences the cooling requirements is the size of the openings. The reference room has 2 openings of 0.6 × 1.6 m, i.e. 1 m^2, with a height/width ratio of 2.6, for a surface area of 36 m^2. Windows’ area is 5.5% of the floor area.

If we apply the simple criteria of summer comfort, the SIA 180 Swiss standard asks for

– a flow rate of 10 m^3/m^2h
– or mono-oriented openings >5% of the floor area if the depth of the room is ≤2.5 times the height of the room, otherwise openings in opposite walls or in corners are required.

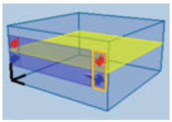
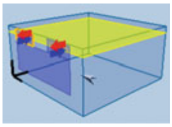
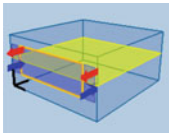
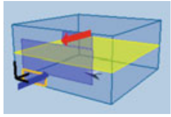
For the reference room this corresponds to a ventilation rate of 360 m^3/h and >1.8 m^2 opening area. The used openings comply fairly well with the second condition. In order to meet the first requirement, a mechanical over-ventilation of 3.8 times the hygienic ventilation is required. Given the analysis carried out when defining the $SEER_{VC}$ indicator (Seasonal Energy Efficiency Ratio of Ventilative Cooling) in [4]—see the following expression—, such a flow rate would consume a lot of electricity with $SEER_{VC}$, even 1.5 time higher than a dual flow ventilation system.

$$SEER_{VC} = \frac{Q_C^{Ref} - Q_C^{\text{Scenario}}}{E_{VC}}$$

where E_{vc} is the energy usage for ventilation.

If these ventilation rate conditions are not met, the SIA 180 requests a verification by dynamic simulation. This requirement could lead some planners to forego the night cooling strategy and use air conditioning. We will explore the possibility of reducing these ventilation rates, as well as the possibility of increasing them in cases

Table 12.8 Window layout scenarios with air flow rates at 5 °C ΔT with outside air calculated with the “Natural Ventilation” module of the DIAL + software

	Vf1	Vf2	Vf3	Vf4
				
$q_{5\,°C}$ [m^3/h]	202	410	676	1210
$q_{5°C}$ [m^3/m^2.h]	5.6	11.5	18.8	34.5
Min* for 50% ren.	34	25	5	4
Ratio /ref.	0.3	0.6	1	1.8

*Overheating hours according to EN 13521 standard

where the solar gains are greater than the optimal gains considered for the reference room.

We have therefore defined 6 ventilation scenarios (see Table 12.8) of which 4 correspond to different positioning or way of opening of the two windows we considered up to now.

- The first considers an opening of 30%, which would correspond to the same openings as the reference room but tilted 15 cm (15° angle).
- The second considers an opening of 60%, which would correspond to the same openings, but lying with dimensions 1.6 width × 0.6 height (instead of 0.6 width × 1.6 height of the reference room) and positioned at the same height.
- The third one is the reference room, with the two openings in vertical, 0.6 width × 1.6 height, with regular turn way of opening.
- The fourth scenario considers 180% of the flow rate of the reference scenario, with the two openings positioned 2.3 m apart (one at the top of the fixed glazing and one at the bottom). This scenario has the same openable area as scenario 2 and 3 but arranged differently. It offers 3 times more flow than scenario 2 and 1.8 times more than the reference scenario.

In the following diagram, we have used the abacus from [4] to calculate the flow rate for the vertical window 0.6 width × 1.6 height (left scale) and the horizontal window 1.6 width × 0.6 height (right scale). The relationship between flow rate and window width is linear, which is not the case for the height where we use parabolic curves (Fig. 12.18).

To calculate the flow rates for Scenario 4, with 2.3 m distance between openings, we can use a similar chart produced for the design guidelines in Annex 62 [4] or use the DIAL + software, as we have done in the following table.

As can be seen from the table above that the airflow rate varies greatly depending on the window arrangement. With the same surfaces (2 windows of 1 m^2 each,

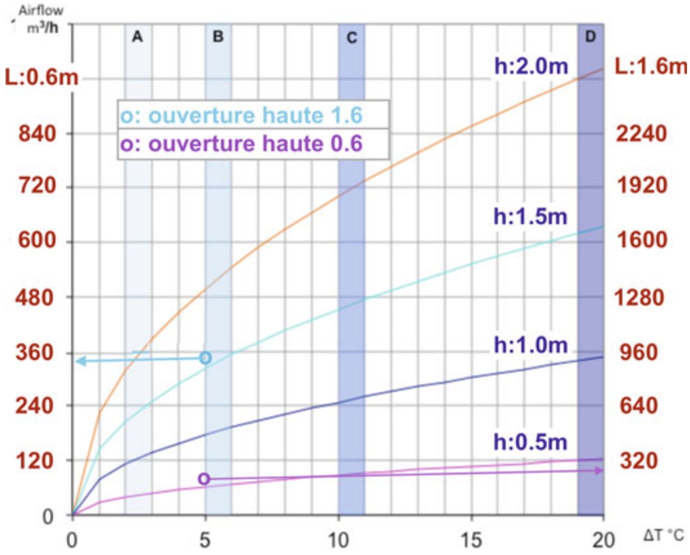


Fig. 12.18 Transformation of the scale of the abacus from [4] to calculate the flow rate of the opening positioned vertically 1.6 height X 0.6 width or horizontally 0.6 height and 1.6 width

completely open), we can obtain 410 m^3/h when the windows are layered horizontally, 676 m^3/h when they are layered vertically or 1210 m^3/h when they are separated by a vertical distance of 2.3 m from each other.

We have indicated for each configuration the time needed to renew 50% of the indoor air in the space. This information is important for the dimensioning of windows in rooms requiring rapid ventilation, such as for example, classrooms or conference rooms, which must remain closed during use and which must be ventilated quickly during short breaks.

It can be seen that the Vf1 and Vf2 configurations are not sufficient to evacuate the pollutants during a 15-min break. The same openings with more height make it possible to renew 50% of the air in the space in 5 and 4 min (Vf3 and Vf4 respectively) (Tables 12.9 and 12.10).

Table 12.9 6 scenarios of airflow variation and opening layout

The 6 airflow scenarios	
$V_m\ q_{SIA2024} \times 1$	Ventilation rate according to SIA 2024, i.e. 2.6 m^3/m^2h
$V_m\ q_{SIA2024} \times 2$	Over-ventilation flow rate 2 X the SIA 2024 flow rate, i.e. 5.2 m^3/m^2h
Vf1 ref X 0.3	Corresponds to 15 cm in tilt opening mode
Vf2 ref X 0.6	2 openings 1.6 width X 0.6 height, arranged at the same height
Vf3 ref X 1	2 openings 0.6 width X 1.6 height, arranged at the same height
Vf4 ref X 1.8	2 openings 1.6 width X 0.6 height, 2.3 m apart

Table 12.10 Comfort and energy indicators for 2 mechanical and 4 natural airflow scenarios

	Vm × 1	Vm × 2	Vf1—0.3	Vf2—0.6	Vf3—1.0	Vf4—1.8
q5°C [m^3/m^2.h].	2.6	5.2	5.6	11.5	18.8	34.5
V_d overheating hours	902	565	189	69	40	26
V_n overheating hours	177	3	0	0	0	0
CRR V_d	0.00	0.73	0.53	0.67	0.73	0.78
CRR V_n	0.58	0.79	0.86	0.90	0.92	0.93

An analysis of these results tells us that for the reference room, it is not necessary to have a flow rate of 10 m^3/m^2h to provide comfort by night ventilation as required in the Swiss norm SIA 180. It is sufficient to double the hygienic flow rate for offices. The optimisation of this flow rate is important, because a high mechanical flow rate would consume a lot of electricity and reduce $SEER_{VC}$ and consequently the ADV_{VC} of the ventilation strategy.

Sizing the windows for flow rates of the order of 34 m^3/m^2h does not greatly improve the energy performance of the night ventilation strategy or comfort. This strategy is even penalizing because it risks increasing the number of hours of discomfort (cold mornings) if the openings are not automated. On the other hand, a high flow rate through the windows improves the daytime ventilation strategy (Fig. 12.19).

In terms of cooling requirements, it can be seen from the graph above that the hygienic flow rate for night ventilation is not sufficient. A double flow rate (5.2 m^3/m^2h) improves comfort for both day and night ventilation. The optimisation of this flow rate, on the other hand, must take into account the performance of the mechanical ventilation system, by calculating the $SEER_{VC}$ and ADV_{VC} and compare to an air conditioning system.

For natural ventilation performance, it can be seen that with only 1.6% of opening surface area (in relation to the floor area), this is sufficient for night ventilation

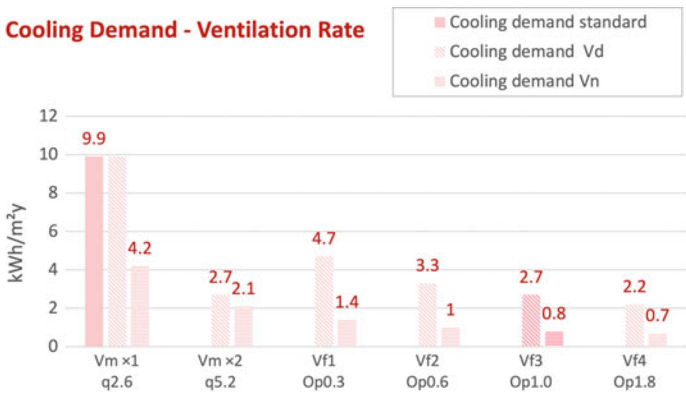


Fig. 12.19 Cooling requirements for different flow rates and arrangement of openings

(scenario Vf1). On the other hand, higher degrees of opening are beneficial for daytime ventilation (≥5%).

A good solution could be to be able to open them 100% manually in regular turn mode during the day when necessary and partially in tilt mode (manually or automatically) during the night. Another solution, which is very appreciated by users, is to split a vertical window into two and have a manual mode in the lower part to open during the day when desired, and an automatic mode in the upper part for the night. This system is also convenient for security issues.

Influence of the mechanical ventilation rate
• The hygienic flow rate of 2.6 m^3/m^2 h is not sufficient for either day or night ventilation, although it does improve the situation.
• A double flow rate (5.2 $m^3/m^2 \cdot h$) is sufficient but the flow rate of 10 $m^3/m^2 \cdot h$ suggested by the SIA 180 standard is excessive.
• When this system is chosen for cooling, the $SEER_{VC}$ should be checked to have at least a value >4 (a bad split air conditioner) and an $ADV_{VC} > 1$.
• The $SEER_{VC}$ must be optimised by optimizing the number of night ventilation hours (less than 700 h of night over-ventilation—a priori 6 h per night) and to centre the operating hours around the coldest hour of the night.
• It must be checked that the system's operating speed in over-ventilation mode for cooling is within an optimum operation range of the air handling unit.
• In the actual reference room, we observed a warming of the air in the distribution network of the dual flow ventilation embedded in the slab, resulting very small temperature variations.

Influence of the natural ventilation rate
• An openable area ~2% of the floor space is sufficient for night ventilation (one 1 m^2 window opening for 20 m^2 of office space open tilted).
• An openable area ~5% of the floor space is optimal for ventilation during hours of use (a 1 m^2 window for 20 m^2 of office space open regular turn completely).
• Prefer high openings and avoid low longitudinal openings.
• If the architectural style of the windows imposes low height (<1 m) longitudinal openings, make sure to have two opening windows with at least 1 m distance between them in height to create higher stack effect than the window height.

12.3.6 Effect of Thermal Capacity

The reference office is made with an "average" thermal mass according to the SIA 180 classification. This corresponds to the following characteristics: concrete floor + uncoated screed with thermal resistance, false ceiling and two external concrete walls (with external insulation) not exceeding 80% of the floor area (Fig. 12.20; Tables 12.11 and 12.12).

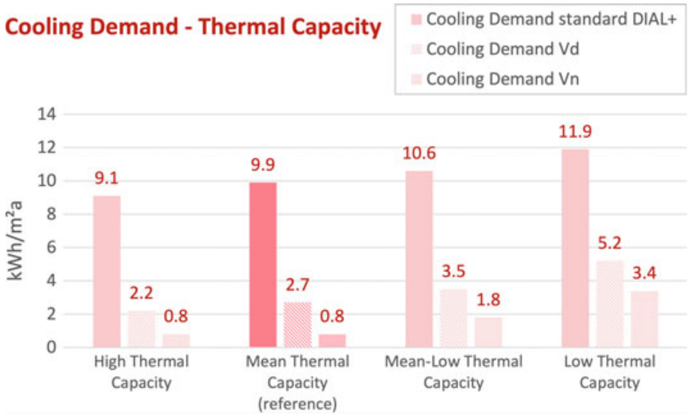


Fig. 12.20 Cooling requirements associated with the three ventilation strategies as a function of the 4 levels of thermal capacity

Table 12.11 Heat capacity according to SIA 180

Heat capacity according to SIA 180	
High heat capacity	Exposed concrete floor or ceiling, + additional concrete surfaces totalling at least 80% of the floor area. The other surfaces are light partitions or suspended ceilings—raised floors.
Average heat capacity	Concrete ceiling or floor with at least a 6 cm thick mineral screed, including the covering if mineral and the other walls in light partitioning with a wooden construction or similar.
Low heat capacity	Lightweight construction (timber construction, steel structure) with lightweight partitions.

Analysing the results of the table and graph, we can see that the impact of thermal mass is quite particular. The cooling requirements do not increase dramatically. Even for the room with a low thermal capacity they only increase by 2 kWh/m^2a (20%) compared to the reference room. The room with high thermal capacity reduced cooling requirements only by 0.8 kWh/m^2a (−8%). On the other hand, the efficiency of the ventilation strategy is more affected by the thermal capacity, especially for the lower values. We can see this in the variation of the CRR, both for day and night ventilation.

It is also interesting to observe how low thermal capacity affects more negatively the cooling efficiency of a low ventilation rate strategy (the V_m mechanical ventilation CRR) (Fig. 12.21).

The impact of thermal capacity on ventilation efficiency is more visible on the comfort indicator. The room with a high thermal mass ensures almost constant comfort (11 h outside the comfort zone) while the room with a low thermal capacity shows 187 h of overheating with the same strategy. Rooms with medium-low and

Table 12.12 Simulation results of comfort and energy indicators with different levels of thermal capacity

	High thermal capacity	Average heat capacity (reference)	Medium-low heat capacity	Low heat capacity
Hours of overheating V_0	830	902	918	971
Hours of overheating V_d	11	40	81	187
Hours of overheating V_n	0	0	10	89
Hours of overheating V_m	110	177	303	514
DIAL + standard cooling requirements	9.1	9.9	10.6	11.9
CRR V_d	0.76	0.73	0.67	0.56
CRR V_n	0.91	0.92	0.83	0.71
CRR V_m	0.85	0.78	0.66	0.45

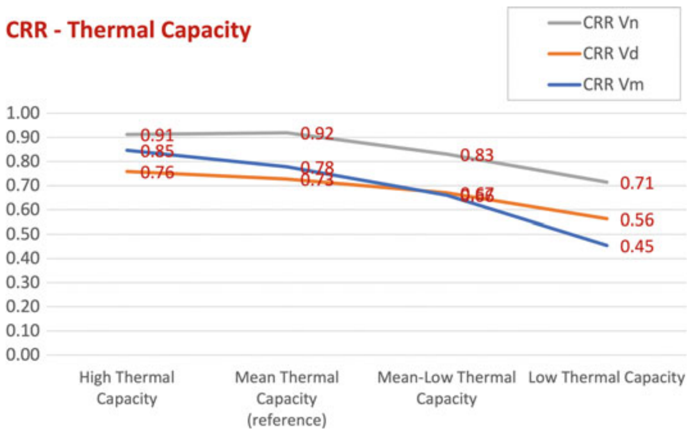


Fig. 12.21 CRR of three ventilation strategies (Night and Day Ventilation V_n—grey, Day Ventilation V_d—red and Mechanical Ventilation V_m—blue) for 4 levels of thermal capacity

low thermal capacity do not ensure comfort under normal conditions even with night ventilation.

A low thermal mass therefore has a greater influence on extreme temperatures than on the average behaviour of the room (cooling requirements without a ventilation cooling strategy). The small effect of thermal mass on average behaviour and the higher sensitivity to extreme conditions has also been observed by other authors [14, 29]. What is interesting to observe, is that a simple screed (medium-low thermal

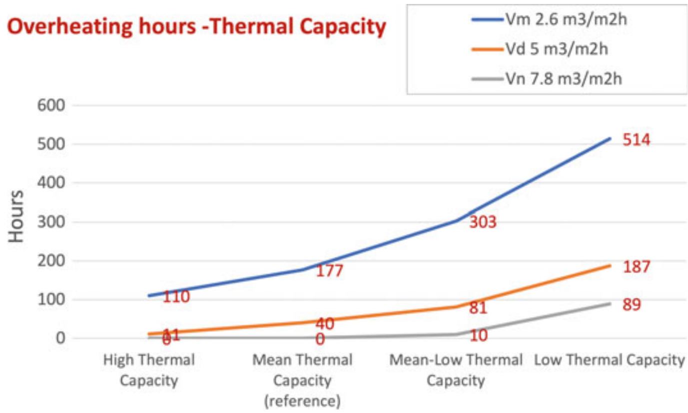


Fig. 12.22 Overheating hours of 3 fan cooling strategies for 4 levels of thermal capacity

capacity) is sufficient to have a very significant effect in ventilation efficiency. This is important for timber and other lightweight constructions where a simple and not expensive architectural choice brings enough thermal mass to make the building thermal response to night cooling more efficient (Fig. 12.22).

As can be seen in the graph above, a room with a low thermal capacity and 50% glass cannot ensure summer comfort under normal conditions of use, even with night-time ventilation (89 h of overheating). With daytime ventilation only, the situation is worse with 187 h of overheating, which is not acceptable. As we can see in the graph, the room with low thermal capacity becomes very sensitive to heat. It is worth exploring this case further, with more and less solar gains, and with different levels of low thermal mass.

12.3.7 Behaviour of the Reference Room with Low Thermal Capacity

For this specific case, we collaborated in this project with the Smart Living Lab (SLL) of the EPFL. The SLL realized an experimental device with two identical offices, one with very low thermal mass (all walls and ceilings with wooden sandwich panels with 18 cm of polyurethane insulation). We varied the thermal mass of the floor with a cement screed, and a wall with compacted mud bricks. We measured the behaviour of the room in order to calibrate the parameters of the DIAL + software, and then we simulated the same ventilation strategies as for this parametric analysis and with 5 variants of low thermal mass. The room is located in Fribourg, with a cooler summer weather than Geneva, and the solar protections of the room are better than the standard values of SIA 2024. The detailed results of these studies are published in [13, 15]. With these small improvements in the standard conditions (g of the blinds,

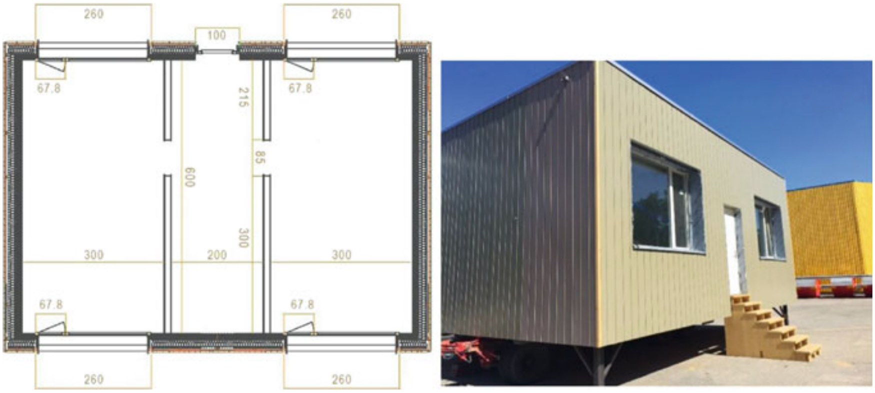


Fig. 12.23 Experimental test room for the study of heat capacity at the Smart Living Lab. One of the 2 rooms has a low thermal capacity and the other is equipped with a raw clay screed and/or a raw clay brick wall

weather in Fribourg, form factor of the room with more walls per m^2 of floor), the experimental room with low thermal mass has only 25 h of discomfort instead of 89 h for the standard SIA 2024 room in Geneva. By adding a simple raw earth screed, these hours of discomfort are reduced to 4. This sensitivity of rooms with low thermal capacity underlines the need for a more careful design, with verification of the choice of glazing, blind properties and thermal mass by simulation (Fig. 12.23).

As thermal capacity has less influence on the thermal behaviour of the building than solar or internal gains, especially with an efficient natural ventilation strategy, the SLL looked at the real energy benefit by taking into account the grey energy that becomes important when concrete is used to increase thermal capacity. As the differences between high and medium capacity are small, the environmental impact (primary energy, CO2 equivalent) of concrete is greater than the energy benefit.

The results of the life cycle assessment therefore show that the average thermal capacities (S3, S4) are globally the most interesting, especially if the thermal mass is provided by natural materials with low carbon impact and low grey energy, as is the case with compacted raw earth [13–15].

Behaviour of timber construction

In view of the importance of the results of the study in the previous paragraph and taking into account the complexity and sensitivity of the dynamic behaviour of a light room, we have specially analysed the behaviour of a wooden room for the standard conditions of use and the climate of Geneva. We would like to answer the following questions:

1. Is at least a screed or other heavy element absolutely necessary in a wooden construction?
2. Can an optimised timber construction withstand a heat wave or cope with climate change?

Table 12.13 Overheating hours and maximum operating temperature of the experimental room in Fribourg as a function of its thermal capacity

Construction of the premises	SIA 180 classification	Hours of overheating	Maximum temperature [°C]
S1. Wood—Polyurethane	Light	25	31.3
S2. Wood + plaster	Light	9	30.7
S3. Cement screed	Low average	4	30.1
S4. Clay bricks	Low average	0	28.7
S5. Clay screed and bricks	Average	0	28.2
S6. Concrete	Important	0	26.9

In order to answer these questions, we have further optimised the other sensitive parameters other than thermal mass for variants S1 and S3 in the Table 12.13. We have thus chosen:

- A more efficient lighting system with 12 W/m^2 instead of the 15.9 W/m^2 of the standard variant.
- Very light colours on walls, floors and ceilings to increase daylight autonomy to 57% for 500 lx, 76% for 300 lx or 81% for 500 lx in the main use area (4 m deep) (we took 76% autonomy in the calculation).
- High-performance exterior movable blinds with a g-value of 0.15 instead of 0.28 specified in the SIA 2024 standard conditions.
- For S3, we created an "optimisation 2" by reducing the glass surface to 30% instead of 50% of the reference room in addition to the other improvements.

This last optimisation not only reduces solar gains, but it also reduces daylight autonomy and therefore increases internal gains. According to a simulation with DIAL + , the average autonomy for a 500 lx lighting level drops from 57 to 37% and for 300 lx from 76% to 64%. If we consider the autonomy at 500 lx in the area of main use, we go from 81% to 53%. We took an autonomy of 76% in optimisation 1 and 53% in optimisation 2. Although the solar gains are lower for optimisation 2, the internal gains are higher with a lower autonomy, which gives lukewarm results (Figs. 12.24 and 12.25; Table 12.14).

As we can see from the table, although the cooling requirements are drastically reduced (6.4 to 7.4 kWh/m^{2}a instead of 9.9 for the reference room), there are still hours of residual overheating, and even with night ventilation, we have respectively 47 and 36 h out of the comfort zone for the room with low optimised thermal capacity. Only the room with screed (medium–low thermal capacity) guarantees comfort when it is optimised. Unfortunately, optimisation 2, although it reduces solar gains, increases electricity consumption for lighting, so this optimisation is not interesting.

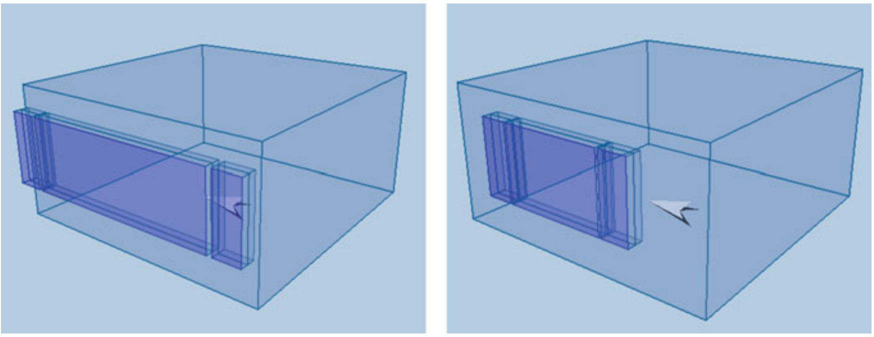
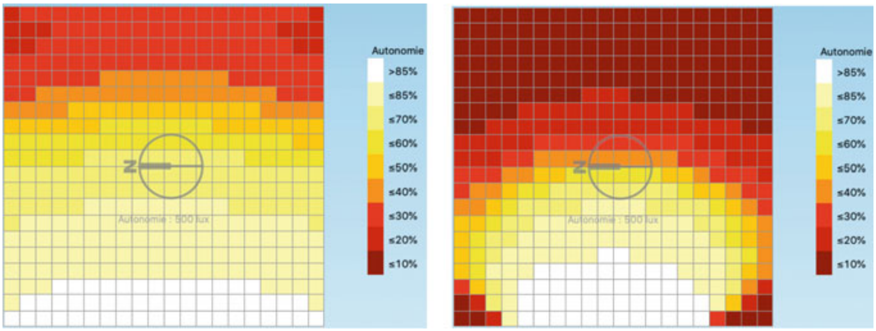


Fig. 12.24 Glazing of the reference room (and of optimisation 1) and optimisation 2 with the glazed surface reduced to 30% of the façade instead of 50% of the reference room



Autonomy optimisation 1

57% at 500 lux, 76% at 300 lux

81% at 500 lux zone 153%

Autonomy optimisation 2

37% at 500 lux, 64% at 300 lux

at 500 lux zone 1

Fig. 12.25 Daylight autonomy of the two rooms (DIAL + simulation)

So, the answer to question 1 is that without a screed or other element with thermal mass, the comfort without cooling for a wooden desk with a wooden or metal structure is critical. With the low number of overheating hours for the optimised room, it would be possible to guarantee comfort with a ceiling fan, or with underfloor geothermal cooling of 10 W/m^2 without a cooling machine.

We simulated the optimised room with screed and found only 9 h of overheating on the hottest summer days. As we can see from the following weather diagram, these few hours of discomfort take place in June and August, which correspond to the weather in summer 2003 according to Meteonorm's max file. So, the answer to question 2 is yes (Fig. 12.26).

A building that can withstand heat waves is also a building that will withstand climate change, at least until 2060, as we will see in the following paragraphs.

Table 12.14 Comfort and energy indicators for optimised low thermal capacity rooms

	Average heat capacity (reference)	Medium-low th. capacity—optimised premises	Low th. capacity—optimised room 1	Low th. capacity—optimised room 2	Low th. capacity—non-optimised room
Hours of overheating* V_0	902	667	673	889	971
Overheating hours* V_d	40	43	95	80	187
Hours of overheating* V_n	0	0	47	36	89
Hours of overheating* V_m	177	72	253	212	514
Standard cooling requirements	9.9	6.4	7.4	7.1	11.9
CRR V_d	0.73	0.67	0.58	0.61	0.56
CRR V_n	0.92	0.84	0.72	0.73	0.71
CRR V_m	0.78	0.70	0.49	0.54	0.45

*Overheating hours according to EN 13521 standard

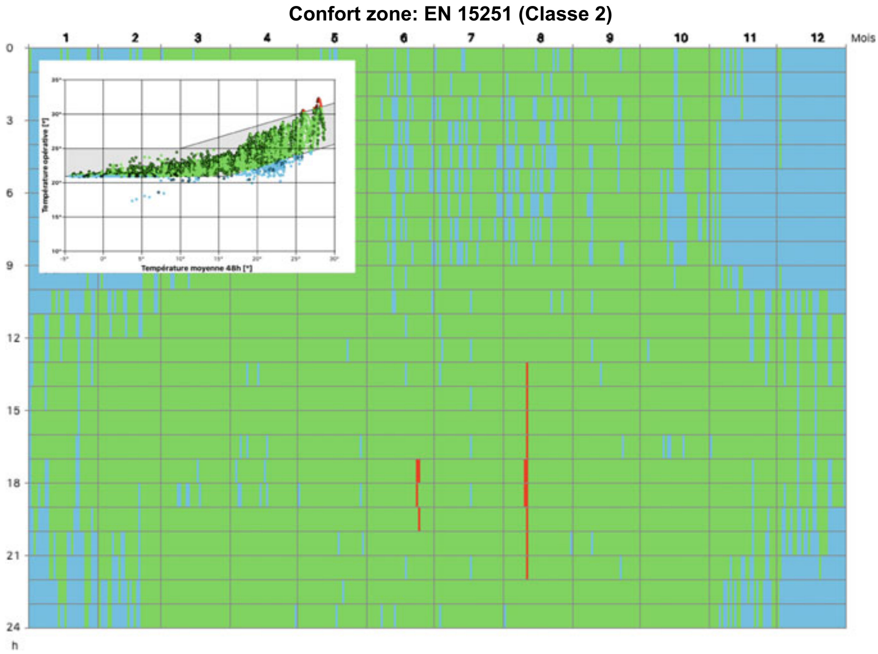


Fig. 12.26 Time diagram for a wooden building in Geneva with optimised solar gains and a screed on the ground, for a year with strong heat waves in June, July and August (as in 2003)

A wooden construction, therefore, requires special design attention in order to offer it a little thermal mass (a screed or a solid brick wall), good blinds and good natural light autonomy.

In addition, we simulated a light room with 84% glass surface. With night-time ventilation, comfort is barely guaranteed (14 h of overheating) for an average year, but such a light, glazed room would not be able to withstand heat waves without additional cooling. The 43 h of overheating already appear in the month of March with perfect solar protection management, and become 151 with poor blind management (Fig. 12.27).

Influence of the thermal capacity
• The influence of thermal capacity is low for a well-designed room from the point of view of solar protection, reasonable internal gains and intelligent ventilation..
• The influence is also small for mechanically cooled buildings.
• Thermal capacity is important for extreme conditions (heat peaks) where the total absence of massive elements becomes critical. A non-optimised room without thermal mass requires cooling.
• A light wooden office building can offer comfort without air-conditioning, provided that the blinds, night ventilation are perfectly managed and at least a single element of average thermal mass (screed or solid brick wall) is present.

(continued)

(continued)

Influence of the thermal capacity
• A light wooden office building, without a single element of medium thermal mass can offer comfort with a light floor cooling with 10 W/m^2 of geothermal cooling or with ceiling fans, buried pipe ventilation or adiabatic cooling of 10 W/m^2, provided that the blinds and night ventilation are perfectly managed.
• Too much thermal mass does not provide an energy added value that compensates for its grey energy or CO2 impact. If it is present for constructive reasons, it must be preserved, but it is not necessary to impose it for comfort or energy reasons.
• An average thermal mass is a good compromise between grey energy and summer thermal comfort for a wooden light construction.
• A low thermal mass is good for grey energy, but the total absence of thermal mass makes the building sensitive and requires perfect control of the blinds and night ventilation.
• The combination of low thermal mass (even with screed and optimum design) with a high proportion of glazing makes the building sensitive and the building control system or occupants have no room for error.

12.4 Ventilative Cooling Parametric Study for Climate and Microclimate Variations Under Swiss Climates

Parametric studies in bibliographic references analyse ventilative cooling mostly for buildings built before 2010. Near zero energy buildings, which are more and more the common case today, and the buildings designed according to new regulations have very different thermal behaviour in respect to traditional buildings. High level of external insulation is generally required in all European countries, even the most southern regions. A 6–10 cm insulation on a building in southern countries creates a completely different thermal behaviour also in summer conditions. In the central European climates, the minimum insulation thickness is 16–20 cm, and high-performance envelopes have 25–32 cm insulation. Air tightness and high-performance double or triple glazing are also removing any dissipative possibility of the buildings that become very sensible to solar and internal heat gains. In Switzerland solar gain control is compulsory in the last 20 years and changed the architectural landscape of the country. However, this regulatory situation is far to be the rule in Europe, even for the hot countries where glazing is more exposed to sun. The parametric analysis of ventilative cooling is different under solar control conditions or not. The higher overheating risk comes from the sun and not from outdoor temperature, especially in central and north European climates.

This section analyses the climate and design parameters for this type of constructions and conclusions may be in some cases different from the analysis on the traditional buildings in past research. Traditional buildings for example in Central Europe could operate with reasonable degree of discomfort without night cooling. With the new construction regulations, with high insulation levels, high airtightness, summer

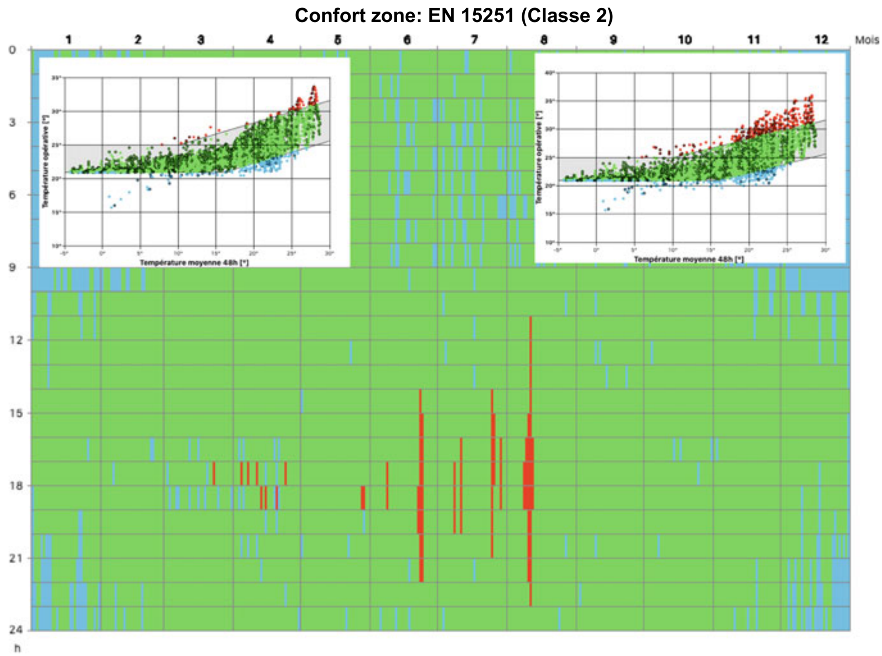


Fig. 12.27 Time chart for a room built in wood, located in Geneva, 84% glazed, with a screed on the floor, for a year with strong heat waves in June, July and August (as in 2003). On the top right is the EN 13251 comfort graph for perfect management of the blinds (43 h of overheating) and on the left, with a poor management with 151 h of overheating

comfort is impossible without night cooling or air conditioning. Another parameter that changed during the last 2 decades is the ventilation rates. Energy saving objectives and absence of smoking in the buildings divided the mechanical airflow by a factor of 2.

This section analyses the thermal behaviour of the reference office room under different climatic, microclimatic and design influences. Also in this section, the parametric analysis calculates the comfort and energy key performance indicators, but in this case considering climatic and microclimatic cases. Results show that with a ventilative cooling strategy, heat island effect in Geneva has little effect on indoor thermal comfort. Heat waves, becoming more intense and especially more frequent, have more significant negative impact. However, despite the negative impact of heat waves, comfort and energy indicators evaluated with dynamic simulation using DIAL + show that ventilative cooling still remains the answer to handle this new situation without increasing energy consumption of the building stock. Using the same method, simulation results using the predicted climate for 2060 show that ventilative cooling is able, in Switzerland, to mitigate the effect of climate changes. Buildings in these future-climatic conditions can still reach thermal comfort without air-conditioning, and this conclusion is valid for central European climate. Results show that a well-designed building, with adequate solar control, reasonable internal gains and appropriate day and night ventilation strategies, can support heat waves and climatic changes.

12.4.1 Climate Impact in Switzerland

In previous works in bibliography [16, 17], we find a characterization of the cooling potential of a climatic zone according to the weather conditions, without taking into account the needs of the building to be cooled. An innovation of Annex 62 is to evaluate this potential by considering the building as well. This consists of simulating a building according to the climatic conditions and evaluating the performance indicators. With the Annexe 62 introduction of energy performance indicators for ventilative cooling [4], in addition to the potential of a climate to provide comfort (calculation of hours in the comfort zone), we can assess the potential of a climate to reduce the cooling requirements for air-conditioned rooms. This can change current practices that tend to make air-conditioned buildings preferably closed without the possibility of opening the windows.

We evaluated the comfort indicators and the CRR for the office use for 6 typical Swiss cities. In order to characterise the climate of these cities with a single indicator, we calculated the number of hours when the outdoor temperature is above the comfort temperature according to ISO 7730 (mostly >26.5 °C). The number of discomfort hours of the outdoor air is low. This shows that the cooling potential of ventilation is high. It also indicates that the problems of summer thermal comfort for all Swiss climates are mainly a question of poor management of solar shading and poor design of ventilation openings rather that outside high temperatures (Table 12.15).

As we can see from the table, even well protected with good blinds, an office goes from one to two hundred hours of overheating to around several hundred, or even a thousand, in the main Swiss cities, except for mountain locations, where there are almost 400 h of overheating. This is confirmation of the first hypothesis at the beginning of this document, stating that modern buildings do not offer a dissipative element of summer heat. Simply opening the window during the hours of use reduces the hours of discomfort and the need for cold in a very significant way. Over-ventilation at night (Vm) alone does not provide sufficient reduction in cooling requirements and leaves hours of discomfort. Unfortunately, there is no software, as far as we know, that allows us to simulate a combination of window opening during the hours of use and over-ventilation at night by the ventilation system. Natural night-time ventilation, in all weather stations, offers sufficient comfort for the typical room being studied (Fig. 12.28).

Table 12.15 Comfort and energy indicators for office room and 4 ventilation strategies for 6 weather stations according to Meteonorm (typical year 1981–1991)

	Geneva	Payerne	Zurich	Sion	Lugano	La-Ch.-de-Fonds
Hours with Te > ISO 7730 (26.5 °C)	193	105	82	174	161	24
Summer days (Meteosuisse max ≥ 25 °C)	60	47	48	68	66	13
Tropical days (Meteosuisse max ≥ 30 °C)	15	8.1	9.1	16	8.1	0.3
Hours of overheating* V_0	902	880	779	983	1007	396
Overheating hours* V_d	40	4	11	30	30	0
Hours of overheating* V_n	0	0	0	0	0	0
Overheating hours* V_m $q_{SIA2024} \times 1$	177	50	68	104	305	0
DIAL + standard cooling requirements	9.9	7.4	6.4	9.8	12.4	1.9
CRR V_j	0.73	0.84	0.80	0.63	0.38	0.98
CRR V_d	0.92	0.95	0.94	0.89	0.80	1.00
CRR V_m $q_{SIA2024} \times 2$	0.78	0.85	0.81	0.81	0.66	0.95

*Overheating hours according to EN 13521 standard

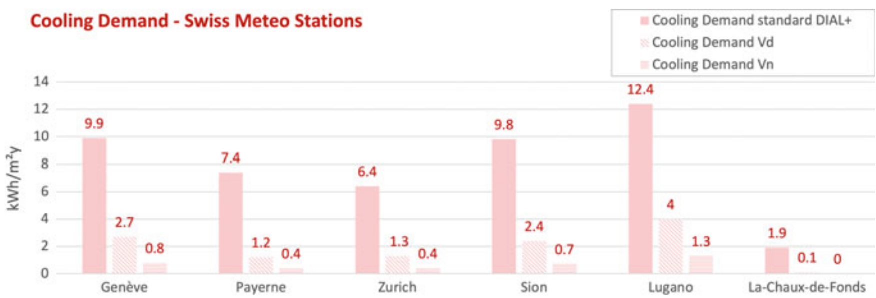


Fig. 12.28 Cooling requirements for 6 Swiss weather stations. Apart from the two extremes of the mountain climate, ventilation cooling strategies have a similarly high potential

12.4.2 *Effect of the Microclimate*

Over the past three to four decades, a number of studies on the microclimate of Swiss and European cities related to passive cooling have been carried out [18, 19]. The first studies are limited to the phenomenological analysis of the heat island, while the most advanced models focus on the calculation of surface and urban air temperatures at a given point in time, presenting the results in the form of a map with the spatial distribution of temperatures [20]. As computing power becomes available, dynamic models are beginning to emerge [21] with predictions of an acceptable degree of credibility. However, we are still a long way from being able to simulate local weather conditions and use them as input for dynamic building simulation software. The reference is still the weather at the reference site of a city. An interesting idea proposed by Tsoka [22, 23] consists in simulating a district with Envimed type software and producing average and extreme monthly temperatures for all the localities of a city using the reference meteorological file and validating them by real measurements on a few localities. Then, introducing these monthly results into the Meteonorm software it produces hourly files specific to a place in the city. But even if we put the energy and time into such an operation, the differences for the same building on the ground and third floors are just as significant as the difference between the reference and the specific site.

To quantify the effect of the heat island on ventilation strategies, we were able to find weather files with complete real measurements (temperature, radiation) at 3 sites in Geneva and we calculated the comfort and energy indicators by simulating the SIA 2024 reference office with DIAL + software as for the other influencing parameters. The urban climate data are for the year 2018. In addition to the "Genève Cointrin" station where Meteosuisse provides the measurements, we have the data for, Rue de la Prairie, at the canton's Engineering School, which is located in a dense urban environment, and for Batelle, at the university campus south of the city in Carouge, which is also on the outskirts at the other end of the city from the airport (Figs. 12.29, 12.30 and 12.31).

In spite of the indicative character of the temperatures of the private weather stations, shared on netatmo.com, and in spite of the errors inherent to these devices which can be badly placed in the sun or near a wall that stores heat, we can observe that in the central zone, and in the south-west of the city, in the Lancy–Bernex

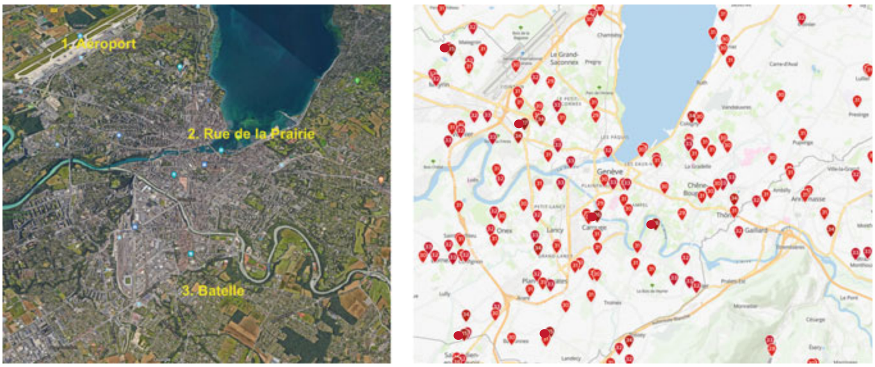


Fig. 12.29 Location of the meteorological sites studied in Geneva and outdoor temperature measurements at private homes by their private weather station shared on netatmo.com on a hot day

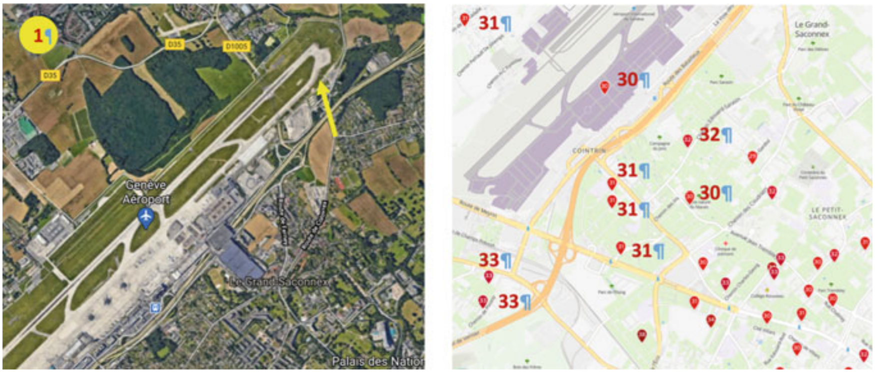


Fig. 12.30 Urban situation of the reference meteorological site and indicative values of the private stations connected in the vicinity

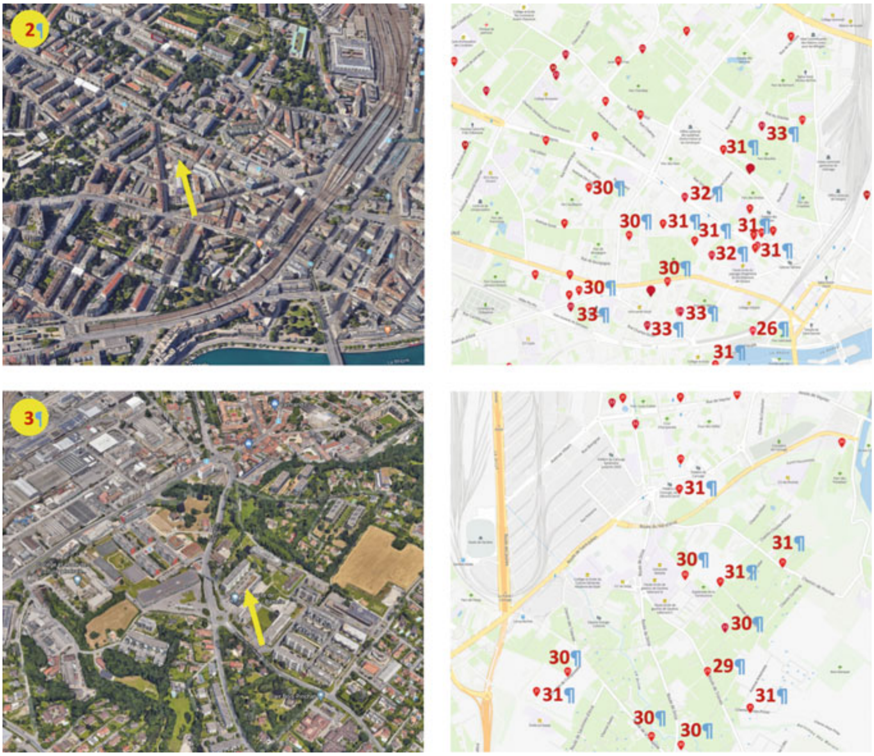


Fig. 12.31 Urban situation of the two analysed meteorological sites in the city and indicative values of the private stations connected in the vicinity

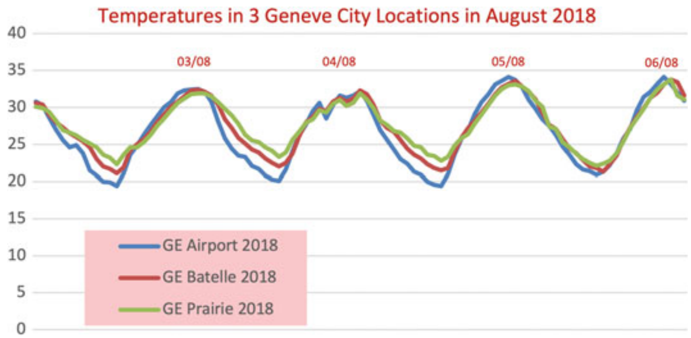


Fig. 12.32 Three weather stations in the city of Geneva to analyse the impact of the urban location on comfort and energy indicators

Confignon zone, the temperatures are higher (on the maps we have hidden some aberrant measurements where the sensor is obviously exposed to the sun). The very slight variation of the daytime temperature is in agreement with the real measurements. In reality we see in an obvious way only a variation for the night minimum temperatures and very slight variation for the day temperature (Fig. 12.32). On a hot day, we observe a minimum temperature of around 20 °C at the airport and 22–24 °C at Rue de la Prairie. The behaviour of the urban climate during a heatwave episode in 2018 shown in the Fig. 12.32 is similar to that simulated and observed in Basel by Wicki et al. [21], where we have higher air temperatures mainly at night. A very comprehensive study by meteosuisse on 5 Swiss cities shows the same phenomenon [24] for Lausanne, Zurich, Basel and Bern, where they could not measure an increase in daytime temperature or an increase in the number of tropical days, but an increase in hot nights with Tmin > 20 °C.

With all these real observations, we are far from the unfounded exaggerations about heat islands of the order of 5 or 7 °C in Geneva, far also from the perception that we should install air-conditioning all over Swiss cities because of urban heat islands. Furthermore, the idea that the airport is a rural area, or that the entire centre is a dense urban area, should be put into perspective, especially in a city on the lake with two rivers running through it. In Table 12.16 we observe an increase in the average temperature in general and in the average number of hot days ($T \geq 30$ °C) over the last 4 decades, but we do not observe an increase in daytime temperatures in summer in the city centre compared to the Cointrin airport. The year 2018, for which we have actual measurements for the 3 sites, is more similar to the maximum scenario of Météonorm, which takes for June and August the temperatures of the year of the great heat wave of 2003. However, this phenomenon, which is commonly called “heat waves” and which is becoming more and more frequent, will be analysed in the next chapter. As far as the “heat island” is concerned, the difference between Geneva Cointrin and the university meteorological sites of Rue de la Prairie and La Batelle is rather in the number of tropical nights (with $T \geq 20$ °C). We have 14 tropical nights at la Prairie instead of one at Geneva Cointrin and 7 at La Batelle.

Table 12.16 Temperature statistics for the reference weather station for 3 urban sites in Geneva

	Meteonorm			Measures		
	Cointrin Average 1981–91	Cointrin Average 91–2010	Cointrin summer max 91–2010	Cointrin 2018	Prairie 2018	Batelle 2018
Average annual temperature	9.9	11.0	12.1	12.3	13.0	12.9
Maximum temperature	30.9	33.6	35.0	34.1	33.8	33.8
Hours ≥26 °C	161	275	567	453	459	481
Summer days $T_{max} \geq 25$ °C	35	51	78	82	73	77
Tropical days $T_{max} \geq 30$ °C	3	6	21	28	21	24
Tropical Nights $T_{min} \geq 20$ °C	2	4	15	1	14	7
Day $T_{max} \geq 30$ °C and night $T_{min} \geq 20$ °C	1	1	9	1	11	7

This makes the evaluation of the effectiveness of ventilation strategies more relevant, in order to quantify the real effect of these urban climate phenomena, as we rely on night-time coolness to combat daytime heat.

The Table 12.17 shows us that the reference office placed in the airport or in the city does not change significantly its thermal behaviour in summer, even if we have 14 tropical nights for the dense urban site in the city centre compared to 1 of the reference site. The heat demand increases by 2.5 kWh/m2 between the reference weather 1991–2010 and the weather of 2018 (a warmer than average year in summer with a significant heat wave). This is plus 25% in relative terms, but low in absolute terms. It should be noted that the reference cooling requirements according to SIA 2024 are 12 kWh/m^2. For the hot year 2018, the cooling requirements vary from 12.4 kWh/m^2 at Cointrin to 13.2 and 13.1 for urban sites. This is 6% more in relative value concerning the cooling requirements without night cooling. But the efficiency of night ventilation is sufficient to make air conditioning unnecessary for an office that can be naturally ventilated at night, regardless of its location in the city. For the daytime ventilation strategy and for mechanical night-time ventilation we see that the potential is even slightly better for Prairie and Batelle, but the situation remains almost the same (Fig. 12.33).

There could be particular situations in cities where there is significant local warming: the presence of a large tarred car park near a ground floor, the particular situation of an unvegetated, narrow and poorly ventilated urban canyon, etc., which could create unfavourable local conditions. These situations are not analysed, as they remain marginal, and they are more in the order of the study of the immediate

Table 12.17 Performance indicators for three meteorological stations in the canton of Geneva in 2018, compared with those of the "Cointrin 1991–2010" reference weather station

	Geneva Cointrin 1991–2010	Geneva Cointrin 2018	Geneva Prairie 2018	Geneva Batelle 2018
Hours with $T_e > 26$ °C	275	453	459	481
Hours of overheating* V_0	902	1014	1025	1026
Overheating hours* V_d	40	87	54	71
Hours of overheating* V_n	0	0	0	0
Overheating hours* V_m $q_{SIA2024} \times 1$	177	246	335	317
DIAL + standard cooling requirements	9.9	12.4	13.2	13.1
CRR V_d	0.73	0.57	0.61	0.60
CRR V_n	0.92	0.86	0.83	0.85
CRR V_m $q_{SIA2024} \times 2$	0.78	0.66	0.59	0.63

*Overheating hours according to EN 13521 standard

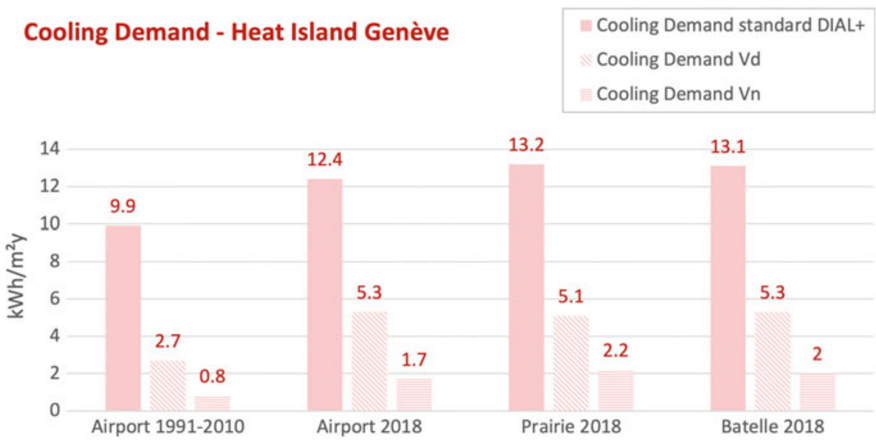


Fig. 12.33 Cooling requirements for the different cooling strategies as a function of the location of the reference office room in the city of Geneva. In all cases, night ventilation is sufficient as a cooling strategy

environment of the building rather than the heat island phenomenon which concerns the whole city. As we calculate the comfort indicators without taking into account the influence of the wind, any microclimatic phenomenon which creates a cool breeze (position in relation to the prevailing winds, position in relation to the lake or rivers) remain additional advantages compared to the analysed strategies which aim at cooling the substance of the building through the use of ventilation. The reference scenario corresponds to the situation where there is no wind, i.e. a possible canyon wind reducing effect is taken into account. Higher surface temperatures of the urban mineral, glazed and metal surfaces, affect seriously the radiative exterior temperature and thus the perceived temperature by people walking in the urban public space but they do not affect the air temperature and the interior climate of buildings. People who complaint for that, could use correctly their blinds or other solar protection and open their windows during night.

Influence of the urban situation
• Summer daytime temperatures, despite beliefs, are not higher in the city than at the airport in the Swiss and probably central Europe cities with similar degree of vegetation.
• Minimum night-time temperatures are 2–4 °C higher depending on the urban environment.
• The cooling requirement in the city do not present a significant variation depending on the urban situation.
• Day and night ventilation strategies are equally effective in the city centre or on the outskirts.
• Although the urban surface radiative temperature may affect seriously the perceived confront of pedestrians in the urban space, air temperature variation is slight and does not affect the interior comfort, especially using a night cooling ventilation strategy.
• For the Swiss (and central European climate) the observed significant rise of night air temperature in the urban sites does not affect seriously night ventilation cooling potential that remains an efficient cooling strategy.

12.4.3 Effect of Heat Waves

As we have already seen by analysing the behaviour of the reference room in 2018, the thermal behaviour can be significantly different from one year to the other. Climate change makes heat waves more and more frequent and more intense. The one in 2003 remained particularly striking because it was the first and the population and public health services of the countries concerned were not prepared to face it. The cities of Geneva, Lausanne and Basel recorded up to 7% increases in mortality during the months of June to August, during this great heat wave [25]. According to MeteoSwiss analyses [26], since the great heat wave of 2003, 5 years were registered with more than 20 tropical days and, among them, the last three are since 2017 and are consecutive. Heat waves are increasing in both number and intensity.

To analyse the effect of heat waves we simulate with DIAL + the comfort and energy indicators for the various ventilation strategies with 4 meteonorm weather

Table 12.18 Comfort and energy indicators for the standard office showing the effect of heat waves with 4 types of weather years from the past

	Cointrin 81–1990	Cointrin 91–2010	Cointrin max 91–2010	Cointrin 2018
Hours with $T_e > 26$ °C	161	275	567	453
Hours of overheating* V_0	863	902	1234	1014
Overheating hours* V_d	21	40	231	87
Hours of overheating* V_n	0	0	0	0
Hours of overheating* V_m $q_{SIA} \times 1$	146	177	550	246
DIAL + standard cooling requirements	8.6	9.9	17.8	12.4
CRR V_d	0.76	0.73	0.48	0.57
CRR V_n	0.91	0.92	0.78	0.86
CRR V_m $q_{SIA2024} \times 2$	0.74	0.78	0.57	0.66

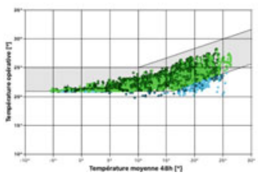
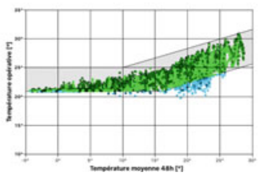
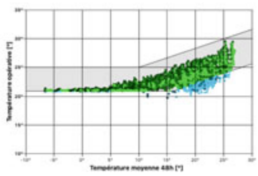
*Overheating hours according to EN 13521 standard

files: 1981–1991, 1991–2010, maximum values in summer (June 2003, July 1994, August 2003), and year 2018 (Table 12.18).

As can be seen from the previous table, heat waves significantly affect the summer behaviour of the building. With a summer like the one of 2003 in June–August, the cooling requirements rises from 9.9 kWh/m^2 with "normal weather for 1991–2010" to 17.8 kWh/m^2, an increase of more than 80%. This increase is 48% compared to the typical cooling requirements for a building according to SIA admitted "standard" conditions. In 2018, a summer that resembles to those of 2019 and 2020 in terms of tropical days (mean heat waves), heat requirements rise by 25% to 12.5 kWh/m^2. Daytime ventilation becomes clearly insufficient. An office without night ventilation, with windows only open during the hours of use (V_d) goes from 40 h of overheating (still bearable) to 231 with a heat wave like the one in 2003 and 87 h with those of 2018, 2019, 2020 (unbearable without ceiling fans). On the other hand, and this is positive, night ventilation remains a valid strategy even with the worst heat wave despite the increase in the average temperature of the room, and this is the main and more interesting conclusion of this analysis (Table 12.19).

If we zoom in on a period of great heatwave with tropical day and night, we can see that the maximum operating temperature is between 28 °C and 31 °C. Admittedly this is 2 to 7 °C lower than the outside temperature, but it is just at the limit of comfort. When interior temperature touches 31 °C, although exterior mean

Table 12.19 Comfort diagram EN 13251 with natural night-time ventilation for cooling for standard weather and two types of heat waves: a high (2003/1994) and a medium (2018)

Average 1991-2010	Max summer (2003/1994)	2018
		
Comfort largely assured	Comfort to the limit all summer long	Periods at the limit

temperature is ~ 25–26 °C with a maximum of 35 °C, many people would feel comfortable only with the use of a ceiling fan (Fig. 12.34).

Although a night-time ventilation strategy is capable of providing 100% comfort during the summer period during a heat wave for the room analysed, being at the limit of the comfort zone makes the indoor climate sensitive to the slightest error of use: few more internal gains, imperfect use of blinds, thermal mass covered by the furniture, additional radiation by a large screen facing the user... This may tilt the comfort out of the EN 13521 comfort zone. As these heat wave episodes become more frequent and intense with climate change, it is advisable to take passive or hybrid measures in addition to night ventilation (geothermal cooling from the ground, radiative cooling from lake water without cooling machines, ceiling fans, natural cross ventilation). It is also necessary to make the control of the ventilation strategy and the thermal gains more efficient (automation of blinds, automation of openings, electrical energy

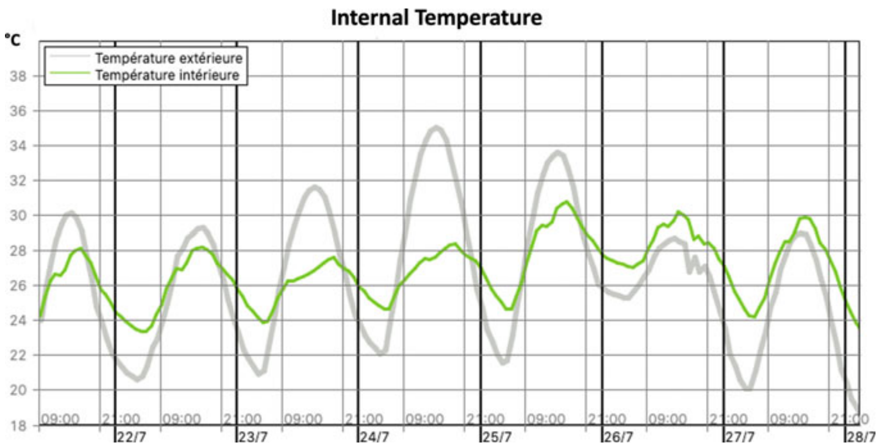


Fig. 12.34 Operating indoor temperature and outdoor temperature with DIAL + one week under a heat wave in July 1994

saving measures). A combination of other passive cooling techniques with ventilative cooling is rising resiliance of the building to extream climatic phenomena that may appear in the future.

Influence of heat waves
• Heat waves are becoming more frequent and intense with climate change that they announce.
• Comfort can always be ensured with the night ventilation cooling strategy even during the worst heat wave.
• Without an effective and well-controlled night ventilation strategy, comfort is not guaranteed despite the significant improvement indoor comfort with day ventilation. A combination of other passive cooling strategies, compatible with ventilative cooling are welcome to increase the feeling of freshness, especially ceiling fans or other soft radiative technics.
• The need for cooling is significantly increased during years with intensive heat waves. Cooling however does not means air conditioning. And although the increase in percentage is significant, the increase in absolute values is low for well designed buildings (less than 10 kWh/m^2).
• Ventilation strategies reduce cooling requirements by 48–86% even during the worst heat wave. Planners must consider them even in combination with air conditioning to reduce energy consumption (avoid it during mid-season for example).

12.4.4 Effect of the Environment Close to the Building

Although on a macro urban scale the climate is not altered in such a way as to significantly influence the behaviour of the building, the vicinity of the building may significantly affect it. Such obstacles may be:

– obstacles in front of or near windows (blinds, vent protections),
– solar absorption and the temperature of objects near the building (trees, other buildings),
– the temperature of the façade itself, creating a boundary layer around the building.

These elements can influence the effectiveness of a ventilation strategy. Either they can warm the air before entering through the window (e.g. blinds, protection of neighbouring building vents or dark coloured facades) or obstruct the airflow. They can do both (e.g. fabric blinds and double skin facades). Trees and neighbouring buildings may shade the window or cool the air.

Tsoka has shown that an urban canyon can raise the temperature locally, especially near the ground where heat is absorbed by the dark-coloured soil when the air stagnates [27] but it can also lower it if it is narrow and prevents the sun from warming the surfaces and keeping the night cool. It can also lower it if it has trees that act as sunscreen and evaporate moisture.

It would be illusory to imagine that, in addition to the effort of dynamic simulation of the indoor climate, building physicists would also simulate the outdoor microclimate. Results of the same study, considering four urban canyons in Thessaloniki

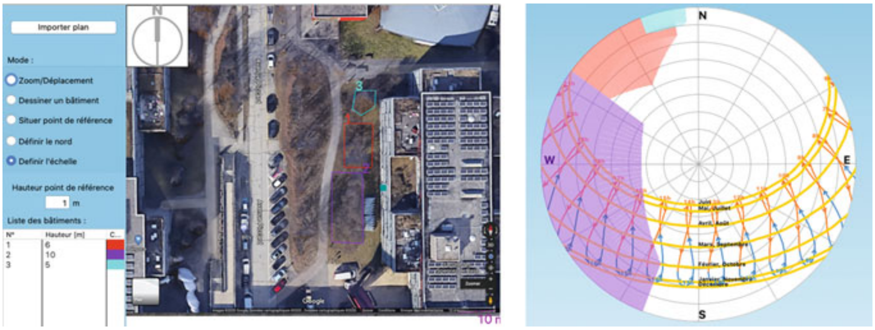


Fig. 12.35 Simulation of tree shadows in front of one of the EPFL buildings. The simulated office is on the ground floor in the middle of the building and the trees in ensemble 1 are 6 m high, those in ensemble 2 are 10 m high and those in ensemble 3 are also 6 m high. The trees are less than 5 m away from the window. The stereoscopic diagram shows that the West façade is sunny between 12 noon and 4 p.m. and shadowed after 4 pm

simulated with Evnimed [27], show that the maximum temperature increase due to the canyon effect is of the order of 1.5 °C on the ground floor and less for the upper floors. This is significant, but it does not concern the whole building. A solution to take into account a pejorative effect would be to use a warm year rather than an average year for the meteorological file. This would pejorate the result more than the warming of around 1–1.5 °C near the ground. On the other hand, we worsen the boundary conditions by excluding the effect of the wind, which compensates for some of the phenomenon. These modelling simplification tricks avoid all the modelling assumptions that can also lead to erroneous conclusions.

More than the outside temperature and the wind, the surrounding environment can modify solar radiation. In the DIAL + software it is easy to simulate near and far obstacles and their effect on the indoor climate, even from a google map image.

In the Fig. 12.35 we can see that the trees are well placed at a distance neither too close nor too far from the building of the Faculty of Basic Sciences at the EPFL (less than 5 m) from the west facing façade. This corresponds to what design guidelines consider optimum in most design textbooks. It can be seen that these deciduous trees do not provide shade between noon and 4 pm. If the building has no blinds on the ground floor and relies only on the shade provided by the trees, the cooling requirements increase from 9.9 kWh/m^2 to 13 kWh/m^2, i.e. we have an increase of 41%. Trees therefore in the case of offices do not provide a sufficient solution for every hour, even if they are placed at an optimal distance and at a favourable orientation (west). Planting the trees nearer to the façade would have counterproductive effects on natural lighting and thus to internal gains. We have simulated the cooling requirements with the protection provided by trees as additional sun protection in the presence of the movable blinds. These requirements are 9.7 kWh/m2 instead of 9.9, resulting in a CRR of 0.02. This is therefore negligible. The effect of these trees is therefore of only a sensitive nature. After 4 p.m. ground floor users can work with the blinds up or even if they are lowered, the solar radiation does not heat the blinds,

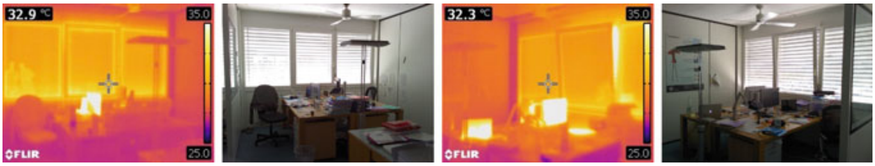


Fig. 12.36 Qualitative visualisation of air heating by an outside venetian blind. When we open the window for ventilation, the air is heated by the solar radiation absorbed by the blind. More the colour of the blind is dark higher the temperature rise it is

and therefore the air that passes through them. As a general rule, the temperature of the leaves of the trees follows the air temperature, which makes the ground floor office in a somewhat advantageous situation compared to another office that would be in front of a tarred car park, or another construction with a dark façade in the sun. It is practically impossible to do without solar protection thanks to trees. If we have good solar protection, trees offer secondary advantages (having a façade in the shade a few hours of the day without the need of using blinds).

The heating of blinds or facades by solar radiation is a real problem, especially for buildings that are naturally ventilated through windows. In the picture of Fig. 12.36 you can see that the blinds behind an open window are much warmer than the air temperature. Here the air temperature was around 28 °C, as was the inside temperature, while the temperature of the blind was over 35 °C. It is difficult to simulate the temperature of the incoming air, because it is a very dynamic environment, but various measurements have shown a temperature increase in the order of 1–3 °C, not counting the radiative effect of the warm surface of the exposed blinds. It is practically impossible to cool behind blinds in the sun, especially if they are not of white or very light colour. Even light grey blinds (the case of the photo) have an absorption coefficient of 0.4.

Blinds are not the only things that warm the air before entering the premises. Double skins or dark facades create a warm air canal or boundary layer, a kind of warm air curtain that goes upwards and envelops the building, preventing fresh air from entering through the windows (Fig. 12.37).

Fig. 12.37 Various situations that can create a boundary layer of warm air near the window. In the last case with fabric blinds, the sun protection not only has a warming effect, it also prevents air from circulating. This building had serious problems with summer overheating and the replacement of fabric blinds with slat blinds solved the problem, even though these blinds are less light-coloured than the existing ones

Many of the buildings in the pictures above had or have problems of summer overheating even though they comply with the conditions of Swiss standards for summer protection (g value of the solar protection <0.1, opening of the windows during summer, thermal mass). If these buildings are not air-conditioned, in other words if they have to rely on natural ventilation, sun protection devices prevent this in the presence of solar radiation. This is the only reason they do not offer thermal comfort.

On a southern facade this limitation of cooling potential lasts all day long, on an eastern facade the blinds limit morning ventilation until 11 o'clock, which is the time that is most beneficial to the cooling of the building or people. On a western facade they prevent ventilation in the afternoon, which is less problematic, as these are the hottest hours of the day when the windows are supposed to be closed in a comfortable room to limit ventilation with hoter air.

It is difficult to simulate these boundary conditions. The phenomena are complex, and the software does not provide automatisms to dynamically modify the g-value of a blind according to the ventilation or to modify the ventilation strategy according to the temperature of the blind. However, the modelling of these phenomena is necessary, because they are the main reason for the overheating of these buildings. In order to quantify the order of magnitude of the effect of the heating of the awning, we added 300 W of heat during the hours of sunshine on the west façade when the window is open on an average summer day when the outside temperature varies between 17 °C and 26 °C. We simulated the temperatures in a 60 cm wide double skin façade, open at the top and bottom across its entire width, with a blind of an absorption coefficient 0.4 (light grey) when the incident radiation is 300 W/m2. This fairly airy situation is not very far from a conventional blind without a screen in front. We have chosen equal inside and outside temperature to quantify pure heating and temperature rise. We can see in the picture that the heating of the awning is of the order of 9 °C up to 35.1 °C with these simulation conditions. The air temperature at the top of the canal rises by 2.4 °C (Fig. 12.38).

To quantify the effect of a grey awning in the west exposed facade, we used Leso-cool software from the solar energy laboratory (EPFL) adding 300 W of heat during the hours when the west façade is sunny and the window is open. This corresponds to a ventilation rate of approximately 300 m^3/h and with an increase in the temperature of the air entering through the window of approximately 3 °C (Fig. 12.39).

The air temperature in the room after 2 p.m. rises by about 0.5 °C on a normal summer day with an outside temperature of about 26 °C. The unpleasant effect of the awning being heated by the sun during ventilation is not only this increase in the average room temperature by 0.5 °C. There is also the effect of the incoming air which is warmer and accentuates the feeling of perceptive discomfort. In addition, a warming of the blind and the air around the window decreases the difference between the indoor and outdoor temperature, and even cancels it out, affecting the effective air flow through the window. The complexity of these phenomena exceeds the ability of professionals to integrate them into standard optimisation simulations. One simple way of taking this phenomenon into account would be to modify the g-value of the

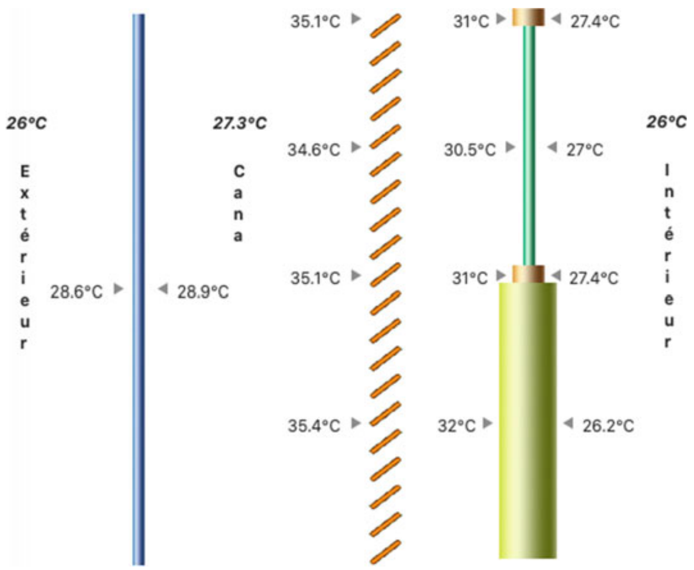


Fig. 12.38 Simulation of temperatures in a double skin façade on one floor with a bottom and top opening 60 cm wide and a blind with an absorption coefficient of 0.4 (light grey)

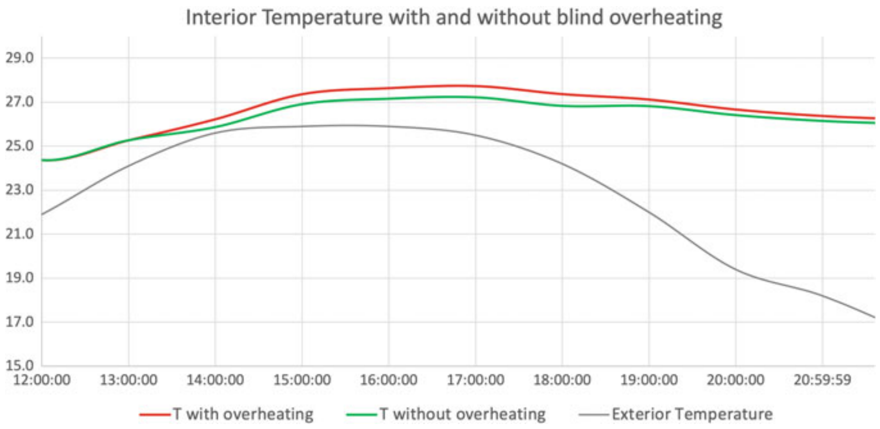


Fig. 12.39 Indoor temperature rise of the reference room (+0.5 °C) simulated with Lesocool with a temperature rise in front of the window of 3 °C, approx. 300 W for an air flow rate of approx. 300 m^3/h

glazing according to the colour of the blind during ventilation hours when the blind is under the sun.

Unfortunately, it is not possible to quantify all the comfort and energy indicators with the effect of overheating an awning. This requires major developments on simple software or a considerable modelling effort for more complex software. But if on an average summer day, we have ½ °C temperature difference over half a day, the comfort and energy indicators must be significantly deteriorated.

Influence of the environment near the window
• Urban canyons can increase the air temperature in the vicinity of the building.
• The changes concern the ground floor more than the upper floors.
• Canyons change temperature, but also solar radiation.
• A row of trees in front of a building has linited influence on the average behaviour of the building.
• Micro-urban changes have a low to medium influence on the entire building.
• The heating of blinds and façades can significantly modify the thermal behaviour of a naturally ventilated room (+0.5 °C on average during sunny hours).
• Warming of the air in front of and obstruction of the window is an important factor that can create overheating.

12.4.5 Effect of the Climate Change

Climate change is starting to be well documented, to the point where we can simulate building behaviour very easily. The latest report of the Federal Office of Meteorology and Climatology MeteoSwiss of 2018 describes the current situation, the expected changes and scenarios per region of Switzerland according to 3 scenarios for 2035, 2060 and 2085 [26]. During summer, the number of summer days as well as the number of tropical days and nights are going to change. Heat waves change in frequency and intensity. The great wave of 2003 with 50 tropical days in Geneva has not yet been repeated, but the years 2015, 2017, 2018, 2019, 2020 follow each other with 30 tropical days ± 5. The question is, what will the weather be like in the future. How it will be, for example, in 2060, when the buildings built or renovated today will not yet be renovated. According to the report by MeteoSwiss on Switzerland's main cities, especially on the Lake Geneva arc and in Ticino, we will go from 15 tropical days in the period 1991–2010 to 40 in 3035, to 60 in 2060 and to around 100 in 2080.

Meteonorm software offers the possibility to simulate the climate of the sites for which it has data, according to the IPCC assumptions on climate change as explained in the 2007 climate report [28]. We have simulated weather according to scenarios B1 and A2 for 2060. As the issue of heat waves is important in summer, we also simulated scenario A2 with summer maximum temperatures.

The pessimistic scenario A2 assumes an average temperature increase of 3.4 °C. As we have seen in the paragraph with heat waves, what is most problematic is not really the increase in the average temperature over the year, but the increase in heat waves. Meteonorm offers us the possibility to create an annual weather forecast according to the A2 scenario with summer maximum temperatures. This is the scenario we have called IPCC A2—Max (Table 12.20; Fig. 12.40).

The first observation on the table and figure is that climate change will cause an increase in cooling requirements. However, this increase is of the same order as an insufficient or poorly managed blind which is very common today. We go from 9.9 kWh/m^2a to 13.4 kWh/m^2a with the B1 scenario of a 1.8 °C increase and to 15.6

Table 12.20 Performance indicators with two climate change scenarios

	Geneva Cointrin	IPCC B1 Geneva Cointrin	IPCC A2—Geneva Cointrin	IPCC A2—Max Genève Cointrin
Hours with Te > ISO 7740 (26.5 °C)	193	307	375	813
Hours of overheating* V_0	902	1095	1182	1276
Overheating hours* V_d	40	109	171	418
Hours of overheating* V_n	0	0	0	29
Overheating hours* V_m $q_{SIA2024} \times 1$	177	405	472	696
Standard cooling requirements DIAL + kWh/m^2a	9.9	13.4	15.6	21.7
CRR V_d	0.73	0.55	0.52	0.36
CRR V_n	0.92	0.83	0.81	0.68
CRR V_m $q_{SIA2024} \times 2$	0.78	0.62	0.58	0.44

*Overheating hours according to EN 13521 standard

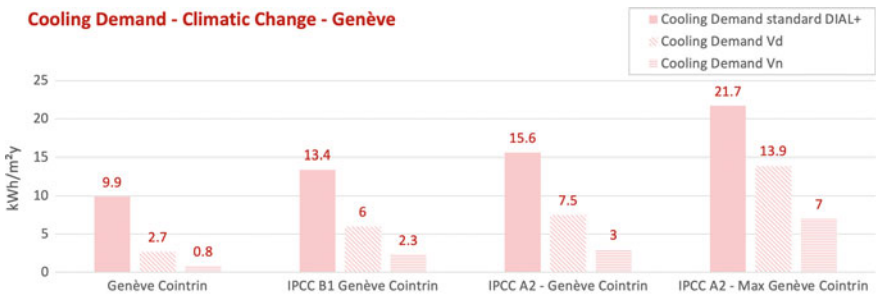


Fig. 12.40 Cooling requirements for 3 ventilation strategies and 2 scenarios

kWh/m^{2}a with the pessimistic A2 scenario of a 3.4 °C temperature increase. It is also observed that this temperature increase is perfectly manageable with an effective night ventilation strategy. On the other hand, the ventilation strategy only during the hours of use (V_d) becomes limited, with 109 and 191 discomfort hours. Comparing these results with the results of paragraph on heat waves, we can deduce that the buildings have already experienced climate change in June and August 2003 and in July 1994. The worst-case scenario of climate change (A2) will have a smaller average effect on buildings than in the summer of 2003. What will therefore change will be mostly the frequency of this phenomenon.

With the A2-max scenario we wanted to project ourselves into a heat wave in 2060 in addition to the worst-case scenario of an increase of 3.4 °C. In this case, which is likely to occur once in the next few decades, the cooling needs are 2.2 times more than today's average scenario, cooling only with daytime ventilation is clearly insufficient, and cooling by night-time ventilation becomes only just sufficient (29 h of overheating). The effect is important, but we may put it into perspective with the effect of an inefficient or badly used solar protection, or with a too much glazed building, which is of the same order. Concerning energy consumption increase for cooling requirements, someone must also put into perspective the reduction of heating requirements. The Table 12.21 shows that in average, the total energy requirements for cooling and heating are smaller in the Swiss climate with both optimistic and pessimistic climate change scenarios. With the extreme A2 scenario with a heat wave in addition, scenario that will happen exceptionally once a decade, there is a 5 kWh/m^2 increase in total heating and cooling requirements but in such a year there must be also more solar renewable energy production.

Table 12.21 Energy consumption indicators with two climate change scenarios

	Geneva Cointrin	IPCC B1 Geneva Cointrin	IPCC A2—Geneva Cointrin	IPCC A2—Max Genève Cointrin
Hours with Te > ISO 7740 (26.5 °C)	193	307	375	813
Standard cooling requirements DIAL + kWh/m^{2}a	9.9	13.4	15.6	21.7
Standard Heating requirements DIAL + kWh/m^{2}a	26.6	21.5	20.2	19.8
Total Heating and cooling requirements DIAL + kWh/m^{2}a	36.5	34.9	35.8	41.5
CRR V_d	0.73	0.55	0.52	0.36
CRR V_n	0.92	0.83	0.81	0.68

What we can retain is that despite the increase in the number of summer days, the increase in the number of tropical days or nights, cooling by ventilation remains an effective technique. The design rules do not change, and the night ventilation strategy will be able to offer acceptable comfort in summer for the typical studied room for the Swiss (and similar Central European) climate. Energy consumption for cooling and heating will not be affected, and lower heating requirements compensate higher cooling requirements. In addition to that, bad news for catastrophists, night cooling may neutralise cooling requirements and globally climate change can reduce building energy consumption for cold climates. However, even night cooling is not selected as a free cooling strategy, higher renewable energy production with sunnier days will contribute to additional non-renewable energy savings and global reduction of the building energy impact.

Taking too many precautions and starting to air-condition buildings "to be ready" for the climate change is not an adequate attitude, it simply contributes to justifying poor architectural design, polluting even more and accelerating climate change.

Heat waves are more difficult to manage, great heat waves will remain exceptional and time-limited events for Switzerland but designing buildings that are comfortable for an average summer also makes it easier to manage an exceptionally vigorous heat wave.

Influence of climate change
• In 2060, whatever the scenario for the progression of the phenomenon, there will be a significant increase in the number of tropical days and nights (from around 20 $\pm$ 5 tropical days today to 40 $\pm$ 10).
• In the worst-case scenario, an average year in 2060 will be somewhat less intense than the year already experienced in Switzerland in 2003.
• The impact of climate change on buildings in summer can be controlled using the same techniques we use today to manage the phenomenon of heat waves.
• Energy consumption of well-designed buildings will not increase due to climate change. Reduction of heating requirements will compensate increase of cooling requirements.
• For the Swiss climate (and equally Central European climate), ventilation cooling is still the most effective passive strategy and is sufficient to neutralise the impact of climate change in summer.

Acknowledgements The results of this chapter have been produced in the framework of the Swiss national research project CoolingVen SI/501297-01t, financed by the Swiss Federal Office of Energy. This work is the Swiss contribution to the IEA Annex 62 project. The original results can be found in French on the site of SFOE.

References

1. Paule B et al (2012) DIAL + Suite: a new suite of tools to optimize the global energy performance of room design. Status Seminar, Zurich

2. Flourentzou F, Pantet S, Ritz K (2017), Controlled natural and hybrid ventilation of school Gymnasiums. J Ventil à paraître 2016 ou début 2017
3. SNR 592024 SIA 2024 (2015) Données d'utilisation des locaux pour l'énergie et les installations du bâtiment. Zurich
4. Per Heiselberg et al (2018) Ventilative cooling design guidelines, IEA EBC Annex 62, ISBN 87-91606-38-1, Aalborg University. https://venticool.eu/wp-content/uploads/2016/11/VC-Design-Guide-EBC-Annex-62-March-2018.pdf
5. Flourentzou F, Bonvin J (2017) Energy performance indicators for ventilative cooling. AIVC conference, Nottingham
6. SN 546 382/1 (2007) Installations de ventilation et de climatisation—Bases générales et performances requises. Zurich
7. SN 520 180 (2014) Thermal protection, protection against humidity and thermal comfort in buildings. SIA, Zurich
8. Christoffer Plesner et al (2018) Status and recommendations for better implementation of ventilative cooling in standards, legislation and compliance tools, IEA EBC Annex 62, ISBN 87-91606-40-3, Aalborg University. https://venticool.eu/wp-content/uploads/2018/10/Recommendations-Standards-IEA_Annex62-October-2018.pdf
9. Kapsalaki M, Carri√© FR (2015) Overview of provisions for ventilative cooling within 8 European building energy performance regulations. AIVC conference—Venticool platform. Madrid
10. https://archive.ipcc.ch/publications_and_data/ar4/wg1/fr/spmsspm-6.html
11. Office Fédéral de L'énergie OFEN (2014) Performance Globale en Éclairage—Global Lighting Performance. Bern, Switzerland, Final Report; Office Fédéral de L'énergie OFEN
12. Paule P, Boutillier J, Pantet S (2015) Shading device control, effective impact on daylight contribution. Cisbat conference, Lausanne
13. Brambilla A, Bonvin J, Flourentzou F, Jusselme T (2018) Life cycle efficiency ratio: a new performance indicator for a life cycle driven approach to evaluate the potential of ventilative cooling and thermal inertia. Energy Build 163:22–33
14. Wang LS, Ma P, Hu E, Giza-Sisson D, Mueller G, Guo N (2014) A study of building envelope and thermal mass requirements for achieving thermal autonomy in an office building. Energy Build 78:79–88
15. Brambilla A, Jusselme T (2017) Preventing overheating in offices through thermal inertial properties of compressed earth bricks: a study on a real scale prototype. Energy Build 156:281–292
16. Artmann N, Manz H, Heiselberg P (2008) Passive cooling of buildings by night-time ventilation. Schlussbericht. Eidgen√∂ssisches Departement fuÃàr Umwelt, Verkehr, Energie und Kommunikation, UVEK. Bundesamt fuÃàr Energie BFE, Duebendorf
17. Chiesa G, Grosso M (2015) Geo-climatic applicability of natural ventilative cooling in the Mediterranean area. Energy Build 107:376–391
18. Oke TR (1982) The energetic basis of the urban heat island. Quart J R Meteorol Soc 108(455)
19. Wanner H, Hertig JA (1984) Studies of urban climate and air pollution in Switzerland. J Appl Meteorol 23
20. Viguié V (2020) Early adaptation to heat waves and future reduction of air-conditioning energy use in Paris. Environ Res Lett
21. Wicki A, Pavlow E, Feignewinter C (2018) Evaluation and modeling of urban heat island intensity in Basel, Switzerland, Climate 2018, 6, 55, mdpi.com
22. Tsoka S, Tolika K, Theodosiou T, Tsikaloudaki K, Bikas D (2018) A method to account for the urban microclimate on the creation of 'typical weather year' datasets for building energy simulation, using stochastically generated data. Energy Build 165:270–283
23. Tsoka S, Tsikaloudaki K, Theodosiou T (2017) Urban space's morphology and microclimatic analysis: a study for a typical urban district in the Mediterranean city of Thessaloniki, Greece. Energy Build 156:96–10
24. Gehrig R, König N, Scherrer S (2018) Städtische Wärmeinsel in der Schweiz - Klimatologische Studie mit Messdaten in fünf Städten, Fachbericht MeteoSchweiz 273, 61 pp

25. Grize L et al (2005) Heat wave 2003 and mortality in Switzerland. Swiss med WKLY 135:200–205
26. Fischer A, Strassmann K, CH2018 (2018) CH2018—climate scenarios for Switzerland. Technical Report, National Centre for Climate Services, 271 pp., ISBN: 978-3-9525031-4-0, Zurich
27. Tsoka S (2019) Urban microclimate analysis and its effect on the buildings energy performance. Phd Thesis, Aristotle University of Thessaloniki, School of Engineering department of Civil Engineering, Laboratory of Building Construction and Building Physics
28. IPCC Fourth Assessment Report: Climate Change (2007)
29. Brambilla A, Bonvin J, Flourentzou F, Jusselme Th (2018) On the influence of thermal mass and natural ventilation on overheating risk in offices. Buildings 8: 47 https://www.mdpi.com/2075-5309/8/4/47
30. Flourentzos F, Pantet S, Ritz K (2015) Controlled natural and hybrid ventilation of school Gymnasiums. International conference on advanced building skins, Bern, Switzerland