建成环境热舒适性评估

瑞士建筑热舒适性规范标准评估经验总结

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摘要：

建筑室内环境的热舒适性是衡量低碳建筑设计的重要标准之一。瑞士的建筑法规对建成空间热舒适性有着很高的要求。当前，瑞士规定建筑热环境的标准有两部，SIA 180:2014 ‘Thermal Protection, Moisture Protection and Indoor Climate in Buildings’和 SIA 382/1 ‘Ventilation and Air Conditioning- General Principles and Requirements’，分别规定自然通风的空间和使用机械通风和采暖制冷的空间。

本文旨在介绍满足瑞士建筑法规要求的热舒适性评价方法，并结合实例介绍相关计算机动态模拟的应用。首先，本文将详细介绍 SIA 180:2014 和 SIA 382/1 中规定的热舒适性评价方法，以及相关的热舒适性评价原则。接下来，本文将通过两个项目实例（一个自然通风空间实例和一个使用机械通风和采暖制冷的空间实例），系统介绍如何通过计算机动态模拟评价建筑设计空间的热舒适性。最后，本文将总结热舒适性评价的标准经验。

关键词: SIA 180:2014, SIA 382/1, 热舒适性评估, 动态模拟, 瑞士热工规范要求

EVALUATION OF THERMAL COMFORT IN BUILT ENVIRONMENT

Experience with the Swiss standards

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Abstract:

Thermal comfort is an important aspect in achieving low carbon building design. Switzerland sets high national standards in thermal comfort in built environment. There are two standards to set thermal comfort benchmarks for naturally ventilated spaces and mechanically serviced spaces respectively. SIA 180:2014 'Thermal Protection, Moisture Protection and Indoor Climate in Buildings' sets the requirements for the comfort, the insulation and the moisture protection for naturally ventilated space. SIA 382/1 'Ventilation and Air Conditioning- General Principles and Requirements' contains the necessary provisions in order to create healthy and comfortable spaces with energy efficient ventilation and air conditioning.

This paper aims to introduce the methods of thermal comfort evaluation for the compliance of Swiss building regulatory requirement, and to explore how dynamic simulation can be integrated into the design process to optimise design decision making. First, this paper will explain in detail the compliance methods for the SIA 180:2014 and SIA 382/1, as well as review the background principles of thermal comfort evaluation. Next, the paper will introduce two case studies that we have recently worked through practice. One case study is a naturally ventilated space and the other case study is a space with mechanical services. At the same time, the dynamic simulation needed for thermal comfort evaluation to inform the environmental design process will be introduced. At last, our experience with the SIA 180: 2014 and SIA 382/1 in relation to thermal comfort evaluation will be discussed.

Keywords: SIA 180:2014, SIA 382/1, thermal comfort evaluation, dynamic simulation, compliance

1 Introduction:

Switzerland sets high standards in thermal comfort in built environment. The Swiss regulations regarding thermal comfort are set by the Swiss Society of Engineers and Architects (SIA) which is Switzerland's leading professional association for construction, technology and environment specialists (SIA，2014). Currently, there are two standards to set thermal comfort benchmarks for naturally ventilated spaces and mechanically serviced spaces respectively.

The SIA 180: 2014 'Thermal Protection, Moisture Protection and Indoor Climate in Buildings' sets the requirements for the naturally ventilated spaces in relation to the comfort, the insulation and the moisture protection. The latest version is issued in 2014. The SIA 180: 2014 standard is applied to all new built non-residential buildings.

SIA 382/1 'Ventilation and Air Conditioning- General Principles and Requirements' sets the necessary provisions in order to create healthy and comfortable spaces with energy efficient ventilation and air conditioning. The current version is issued in 2014. This standard describes the basic criteria for the choice of ventilation strategy and sets out the technical parameters to reduce energy consumption for mechanical ventilation and air conditioning.

Since 2014 when these two standards were substantially updated, we have been working on a series of consultancy projects to evaluate the thermal performance of the designed buildings to ensure the appliance of these two standards. It is necessary to share the experience in the integration of the thermal comfort evaluation into the project procedure to ensure the compliance of thermal comfort standards. This paper will focus on the thermal protection of the SIA 180: 2014 and SIA 382/1 standards in summer case which is the main challenge for compliance.

2 The requirement of thermal comfort:

2.1 The criterion for passive thermal comfort compliance:

The SIA 180: 2014 standard regulates the building envelope, such as external wall, roof, windows and blinds. It sets targets for natural ventilated buildings only, i.e. buildings without mechanical systems. For thermal comfort evaluation, the SIA 180: 2014 standard requires to ensure the hourly indoor operative temperature of a natural ventilated building is within the limits during operation time.

There are three methods to demonstrate the compliance of the standard, namely prescription and dynamic simulation.

For dynamic simulation, defined simulation conditions must be complied with and the calculation report should document all the parameters the models use. The common simulation conditions consist of:

1. The operative temperature should be in the centre of room at the height of 1 metre above the ground. The room air temperature can be used instead of the operative temperature when the mean radiant temperature equals to the room air temperature.
2. Climate data applied in the simulation should be Normal Design Reference Year (DRY) in accordance to the SIA standard 2028; and the weather station which can best represent the building site should be chosen.
3. The observation period should be from the 16th of April to 15th of October in 2011 when the 1st of January is a Saturday. 2011 is the reference year to make sure the simulation has the same number of weekends and holidays.
4. Time step for simulation should be 1 hour or less.
5. 10% of the solar radiation which enters the room should be simulated as convective heat (if this assumption is required in the simulation model).

Further simulation conditions include solar protection, internal heat gain and infiltration rate.

1. The characteristics and control strategies of external shading system should be simulated as designed or existing condition. The wind strength should be taken into account, assuming that the wind speed at shading corresponds to the wind profile at 1m above the roof.
2. Internal heat gain should be simulated as user agreed values. If no agreed value available, the standard value should be applied in accordance with the SIA standard 2024.
    - Occupants: Only the sensitive part of the heat gain should be used and the proportion of convection and radiation is 50% and 50% respectively.
    - Lighting: The proportion of convection and radiation is 30% and 70% respectively.
    - Equipment: The proportion of convection and radiation is 80% and 20% respectively.

3. When the external air temperature is lower than the air temperature, natural ventilation rates at no wind condition determined by a dynamic model should be applied. Otherwise, the natural ventilation rate should only fulfil the health requirement for outside air flow rates per person in accordance with SIA standard 2024.

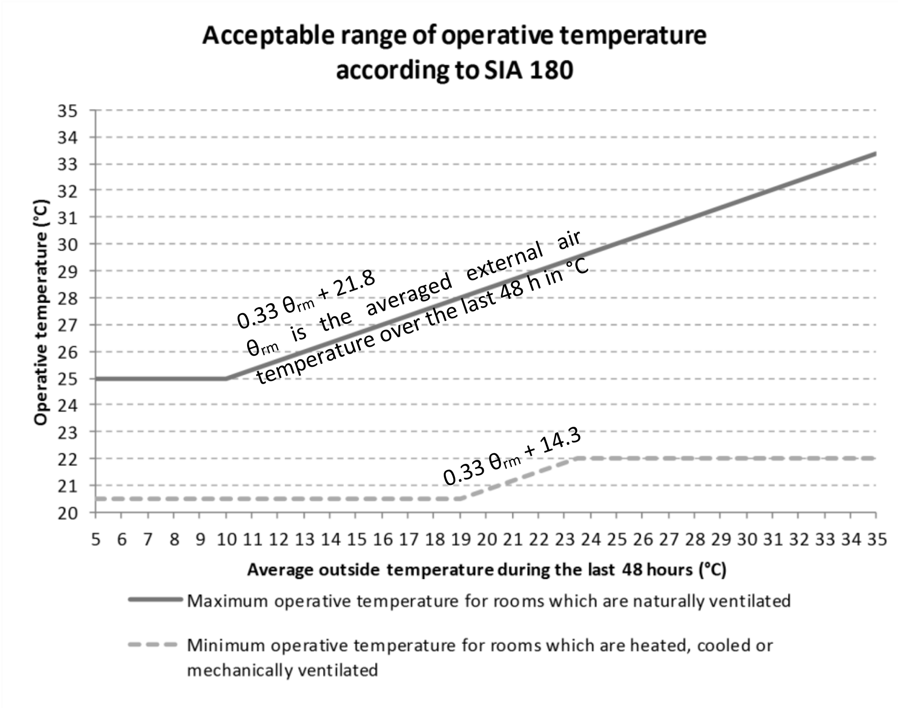

Figure 1: Acceptable range of operative temperature

The requirement is shown in Figure 1. The hourly internal operative temperature during the operation time corresponding to the average external air temperature of previous 48-hour period should not exceed the upper and lower limit at all to satisfy the comfort requirement. Otherwise, planning permission will not be granted. If there are hours above the blue line, it does not simply imply that a mechanical system should be installed at this point. If the initial evaluation of a design suggests there would be hours above the operative temperature up limit, improvement of the building envelope should be improved first with the adjustment of the natural ventilation strategies. It can be cost effective measures to eliminate the overheating hours when external air temperature is relatively high, while it can be more difficult to eliminate overheating hours when external air temperature is low. Investigation of the use of the building to reduce the internal gain can be effective. The demonstration of meeting the thermal comfort requirement is required for planning permission.

2.2 The criterion for active thermal comfort compliance:

If it is impossible to eliminate the unmet hours, mechanical systems are considered to add to the design. The SIA 382/1 which is the regulation for sizing the cooling and heating systems for new built non-residential buildings.

Dynamic simulation can be applied to demonstrate compliance. The common simulation conditions that must be complied with consist of:

1. The external shading system should be simulated as it is closed when the solar radiation is greater than 200W/m^2 on a facade and the operative temperature in the room is comfortable or too warm. The wind strength should be taken into account, assuming that the wind speed at shading corresponds to the wind profile at 1m above the roof.

2. Internal heat gain should be simulated at 120Wh/m^2 as the sum over 24 hours, distributed evenly over 24 hours. The proportion of convection and radiation is 50% and 50% respectively.
3. The infiltration rate should be set at 3m^3/ (h•m^2). External air flow volume should be increased to 10m^3/ (h•m^2), if the operative temperature in the room fixed on a temperature limit and the outside air temperature is lower than the ambient air temperature. The supply air temperature should be set as the external air temperature (corresponding to no heat recovery).

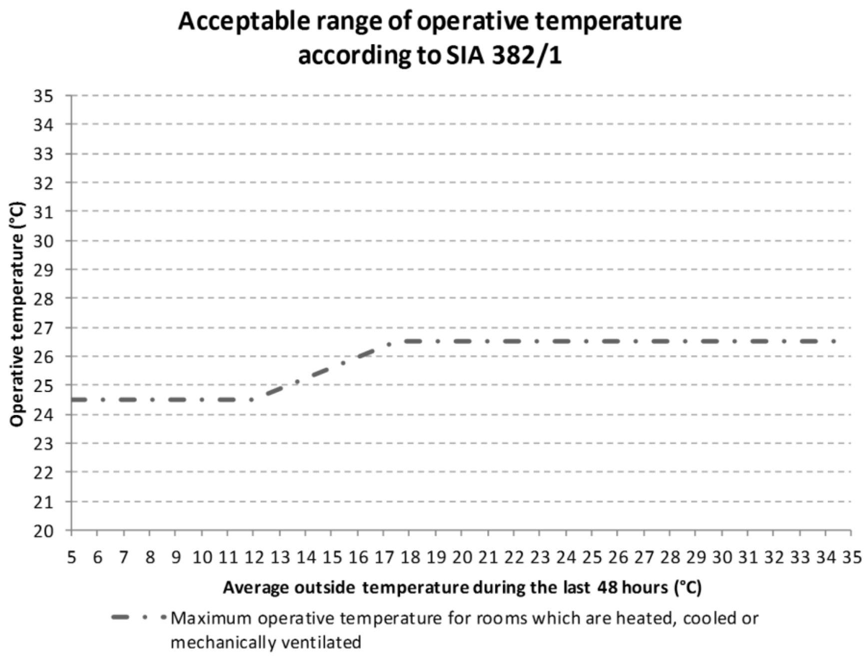

Figure 2: Acceptable range of operative temperature

Figure 2 shows the acceptable hourly operative temperature during the operation time corresponding to the average external air temperature of previous 48-hour period should be less than red line. If a room is mechanically serviced, up to 100 hours are allowed for operative temperature to exceed the upper limit to fulfil the standard.

2.3 Principles of thermal comfort evaluation:

Thermal comfort is defined as the condition of mind that expresses satisfaction with the thermal environment (ASHRAE, 1992). As Auliciems and Szokolay (2007) pointed out the thermal comfort does not only depend on internal temperature, but the external climate, i.e. physiological, behavioural, psychological and cultural adaptation.

The two common approaches applied in thermal comfort research are Predicted Mean Vote (PMV-PPD) method and adaptive models. PMV is a thermal index derived from the heat-balance model of thermal comfort developed by Fanger (1970). PMV predicts the mean thermal sensation of a large group of subjects experiencing a thermal environment specified in terms of mean air and radiant temperatures, air speed, humidity, thermal insulation and metabolic rate. But individual votes are scattered around this mean value and it is useful to be able to predict the number of people likely to feel uncomfortably warm or cool. The PPD is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm. The adaptive model based on the work of Humphrey (1978) is a linear regression model that relates indoor design temperatures or acceptable temperature ranges to outdoor meteorological or climatological parameters.

The principle of the thermal comfort evaluation in SIA 180: 2014 and SIA 382/1 is based on Fanger's work of heat balance models. They express warm and cold discomfort for the body as a whole, but cannot take into account for local discomfort which can be caused by draught, abnormally high vertical temperature difference, too warm or too cold a floor/ ceiling, or too high a radiant temperature asymmetry.

3 Simulation software:

The software package applied to assist building design to comply with the SIA 180 2014 is Heat Transfer in Buildings release 2.10 (HTB2). HTB2 is a model to investigate the thermal environment of buildings in operation developed by the Welsh School of Architecture. It was developed in the light of many years research, in both modelling and monitoring, on the thermal environment of modern low energy buildings (Alexander, 1996). HTB2 is the suitable package since it emphasizes on the performance of the built environment and the operation of the building as an interacting system.

The input data for HTB2 can be categorized into three groups:

Building information:

1. The latitude and longitude of the building
2. The spaces into which the building is to be divided
3. The building fabric linked to or separating the spaces
4. The connections between the spaces to their fabric
5. The constructions of the building fabric with the thermo-physical and transparency properties of the materials used in these constructions
6. The external shading masks of facades

System information:

1. The number, heat output, control and connections of lighting system in each space
2. The number, type, heat output and connections of small power sources in each space
3. The number, heat output and locations of occupants in each space
4. The rates, flow patterns, control strategies of the ventilation systems in each space
5. The number, type, and control characteristics of heating system in each spaces, including maximum output and response characteristics, their radiative/convective output splits and the output connections, the set-points and control strategy of thermostats, automatic time control

Simulation operation:

1. The weather data for the test
2. The configuration of the simulation, i.e. simulation length, the time dependant operating schedule of the building will be operated with respect to time
3. The selection of output data types and intervals

The input files are a series of text files without an overall interface like some other software (for example DesignBuilder, eQuest, IES etc.). The modeller can easily input or change the parameters in the text files. One advantage of not having an interface is the improvement of simulation quality since the required values need manual input without provided defaults. The simulation of a real building requires simplification to transfer it to a simple thermal network space thermal due to the limitations of the modelling procedure and the desire for rapid calculations.

The HTB2 was developed to investigate the dynamic workings of a building, incorporating the many aspects of thermal transport, including fabric conduction, solar gains, incidental gains, ventilation, and heating and cooling systems. (Alexander, 1996). It can calculate the internal air temperature, mean radiant temperature, surface temperatures, solar gains and incidental gains to a space, gains/ losses to the space through ventilation, heating and cooling on short time-scales of minutes and hours.

4 Case studies:

4.1 A case study of a space with natural ventilation:

Project SBB is a retrofit project aims to achieve required comfort in the naturally ventilated train maintenance hall in Olten train station in Switzerland (Figure 3). The space runs along the north south axis with the width of 29 meters and length of 190 meters. The height of the space is 14 meters. The east side of the mall is connected to other spaces in the train station. The main entrance of the mall is on the south. There are windows on the west wall with the total area of 59m^2 as well as skylights on the roof with a total area of 100m^2.

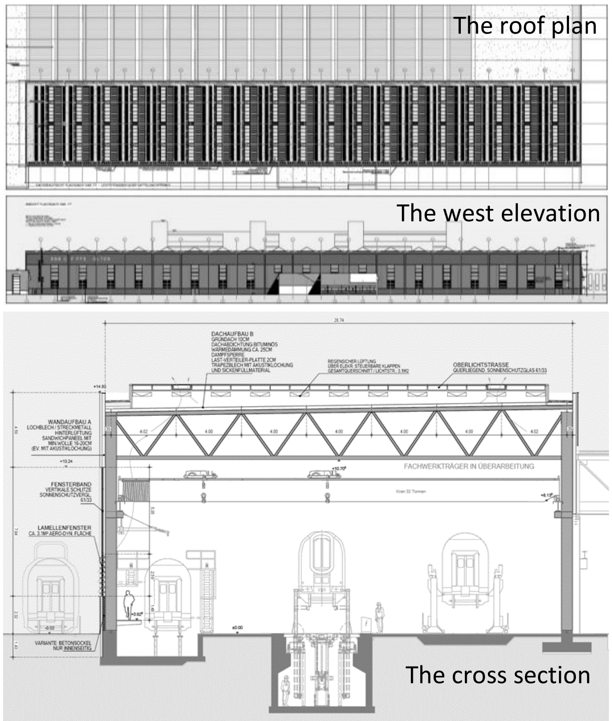

Figure 3: Project hall

The design parameters for the building fabric are shown in table 1.

Table 1: U-values of main building components			
External wall	0.3 W/(m^{2}K)	***Glass G-value***	**33 %**
Internal wall	0.3 W/(m^{2}K)		
Roof	0.3 W/(m^{2}K)	***Glass U-value***	1.0 W/(m^{2}K) windows
Floor	0.3 W/(m^{2}K)		1.6 W/(m^{2}K) skylights

The internal heat gains to the spaces are shown in table 2. The following values are provided by the clients.

Table 2: Internal heat gains		
Lighting	7.88W/m^2	20 hours (M-S)
People	30 people (90 W/person)	20 hours (M-S)
Equipment	23.21 W/m^2	20 hours (05:00 to 01:00) M-S

The profile for hard working has been applied to occupancy, lighting and equipment (Figure 4). The profile is from the SIA standard 2024.

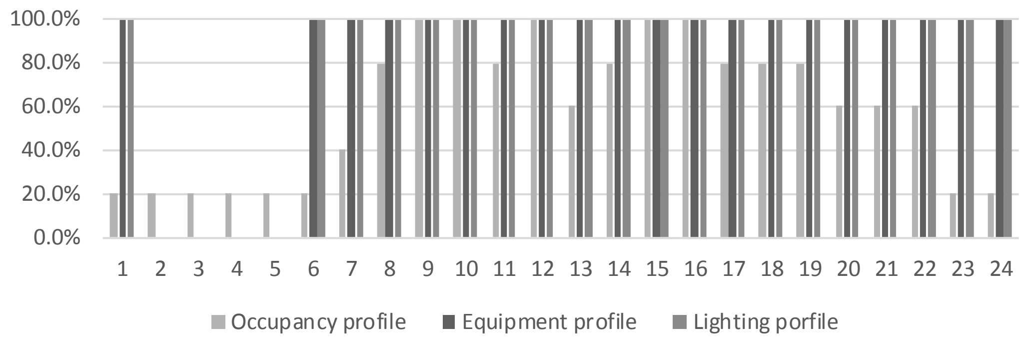

Figure 4: Profile of internal heat gains

First, an air flow simulation was conducted to determine the natural ventilation rate in the maintenance mall for summer case. Winair was used to carry out this study. The case simulated is a windless case when external air temperature is 31.1 degrees (which was the peak external air temperature). What is more, the surface temperature of the train was assumed at 60 degree, and it has been input in the air flow model.

The air flow simulation results suggested that an air change rate of 4.0ac/h can be achieved with the designed roof openings and the west wall openings (Figure 5, 6). Moreover, the air flow simulation shows that there is little stratification of the temperature with the space.

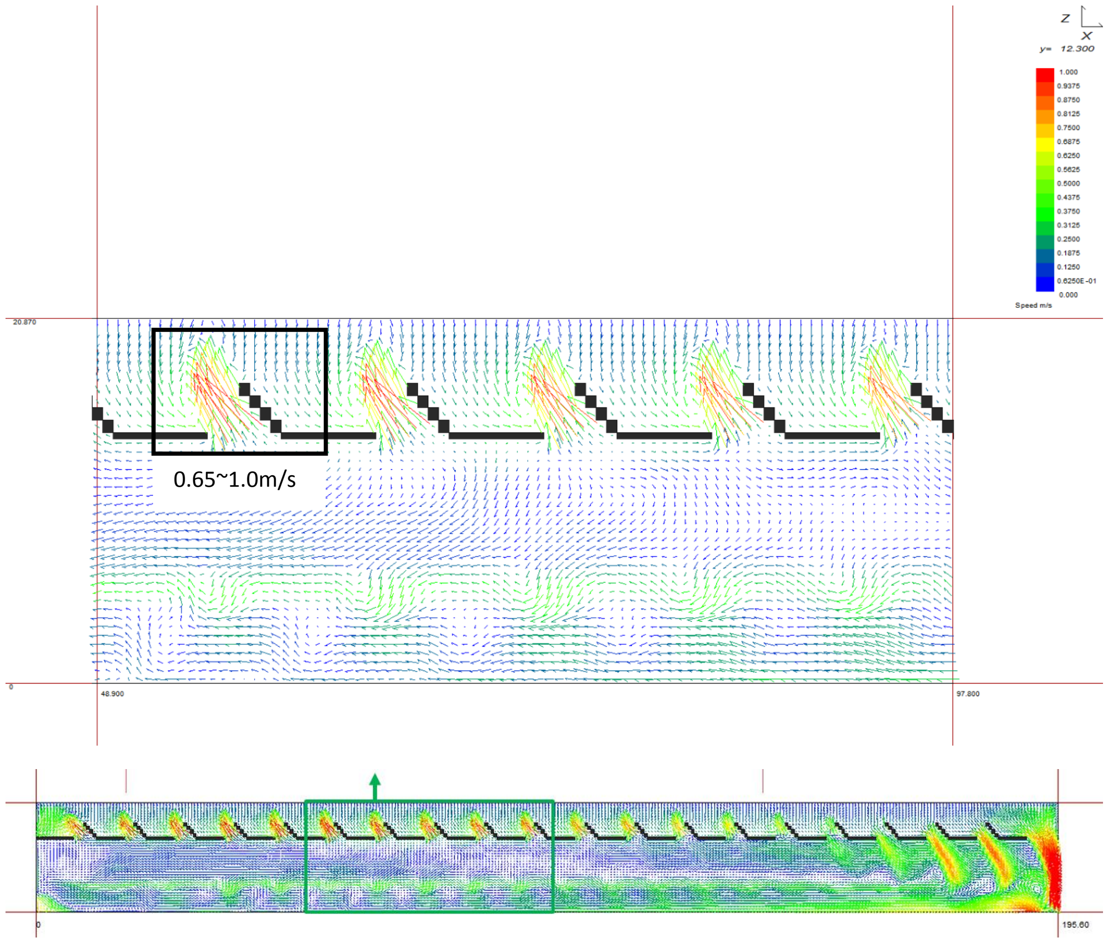

Figure 5: Air flow speed in the long section of the space from the air flow simulation

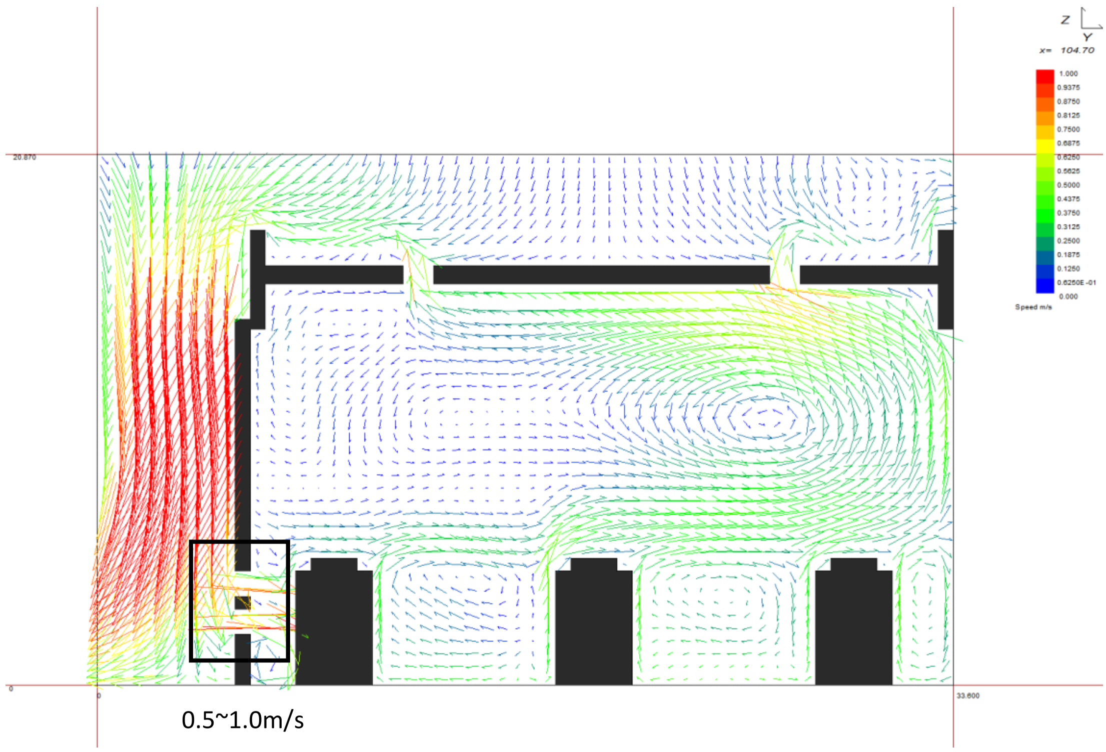

Figure 6: Air flow speed in the short section of the space from the air flow simulation

Based on the calculated natural ventilation rate, a dynamic thermal simulation was carried out to explore the internal thermal condition in the studied space. The peak week performance was chosen for further exploration (Figure 7). The dynamic simulation results indicated that the internal air temperature was 1 to 2 degrees higher than the external air temperature. The mean radiant temperature was 1 to 2 degree higher than the internal air temperature. For 13:00 o'clock on the 10th of July, the external air temperature was 25.5 degree, while the internal air temperature was 26.0 degree with the mean radiant temperature at 27.4 degree. The main reason for the higher mean radiant air temperature was the high solar gain to the space. The peak solar gain could reach 40W/m^2.

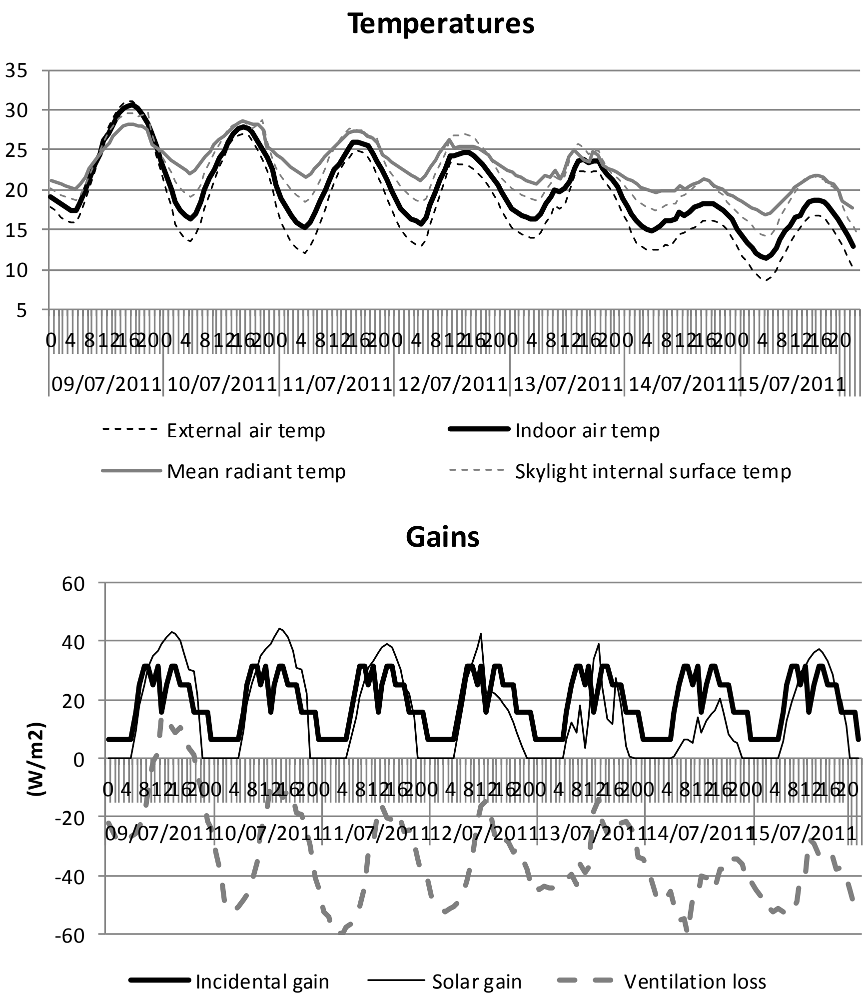

Figure 7: The internal temperatures and gains in the studied space from the dynamic simulation

The dynamic simulation results were then analysed in relation to the SIA 180 standard. The analysis indicated that there are **26** hours when the operative temperature is higher than the limit for natural ventilated space (Figure 8). However, due to the low number of hours and the low external air temperature (16 to 23 degree) when these hour occurred, a suggestion to enlarge the openings to increase the natural ventilation rate was provided. Further evaluation for the revised design indicated that there is **0** hour when the operative temperature is higher than the limit. No mechanical system was required.

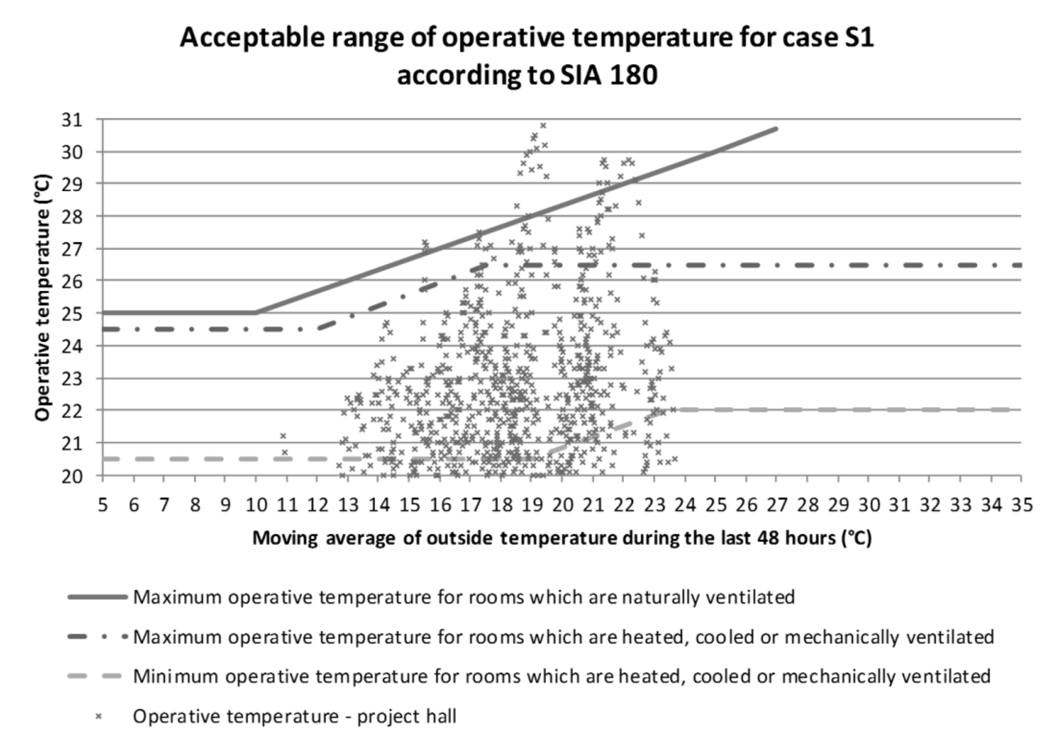

Figure 8: The compliance with the SIA 180 based on the dynamic simulation results

4.2 A case study of a mechanically serviced room:

Project Aeschbauchquartier Gebaude aims to explore whether required comfort can be achieved in a retail space on the ground floor in Zurich in Switzerland (Figure 9). The space faces southwest with the width of 40 meters and a depth of 10 meters. The height of the space is 3.7 meters. There are windows on the three facade with a total area of $108m^2$, and the window to wall ratio is around 50%.

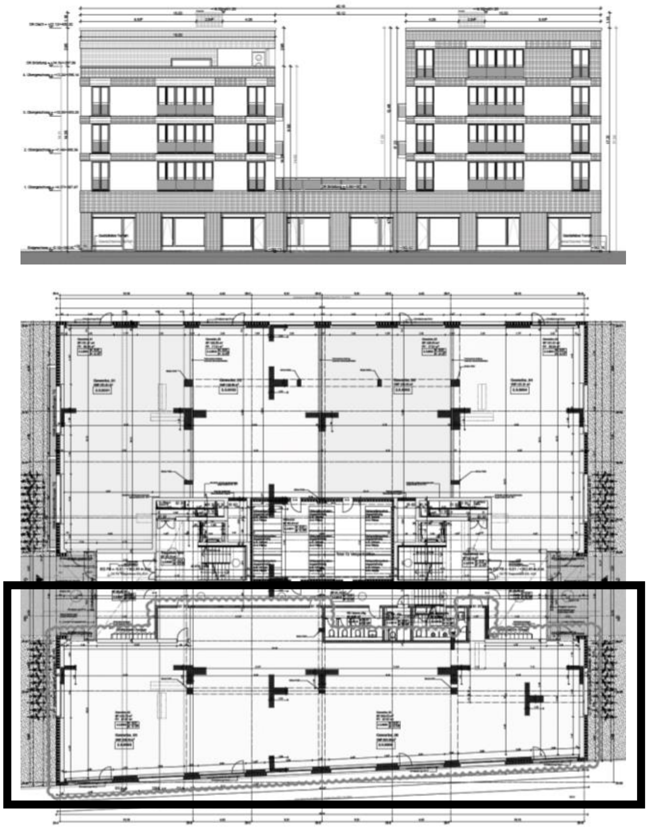

Figure 9: Project retail space

The design parameters for the building fabric are shown in table 3.

Table 3: U-values of main building components			
External wall	0.14 W/(m²K)	***Glass G-value***	**50 %**
Internal wall	1.52 W/(m²K)	***Glass U-value***	0.9 W/(m²K) windows
Roof	0.66 W/(m²K)	External shading system	Overhangs
Floor	0.21 W/(m²K)		

The internal heat gains to the spaces are shown in table 4. The following values are from the SIA 2014 standard.

Table 4: Internal heat gains		
Lighting	33.3W/m²	12 hours from 08:00 to 20:00 (M-S)
People	5m²/ people (70 W/person)	12 hours from 08:00 to 20:00 (M-S)
Equipment	2W/m²	12 hours from 08:00 to 20:00 (M-S)

The profile for retail stores has been applied to occupancy, lighting and equipment (Figure 10). The profile is from the SIA standard 2024.

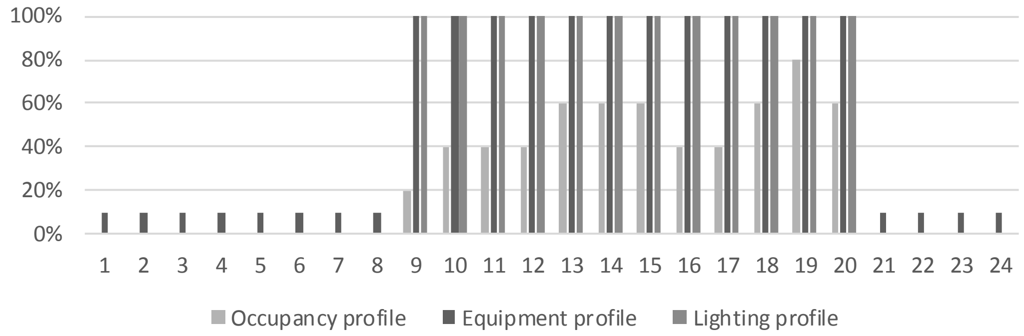

Figure 10: Profile of internal heat gains

The space is mechanically ventilated. The air flow rate is 3.35ac/h, and the input air temperature is 20 degree.

The dynamic simulation has been conducted. The simulation can take into account the surrounding of the simulated space. A shading mask has been generated for the windows where an external shading system or a near building block the solar radiation coming through (Figure 11).

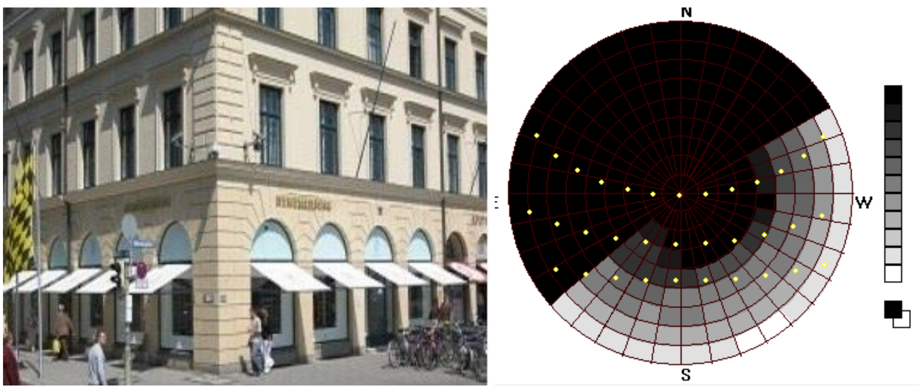

Figure 11: Shading mask of the windows on the northwest facade

The peak week performance was chosen for further exploration (Figure12). The dynamic simulation results indicated that the internal air temperature could rise to 31 to 32 degree. The air temperature was 1 to 2 degrees lower than the mean radiant temperature. The internal gains in the space is quite high, reaching 46.5W/m^2, while the solar gain to the space is 18W/m^2. The mechanical ventilation cannot take sufficient heat away from the space.

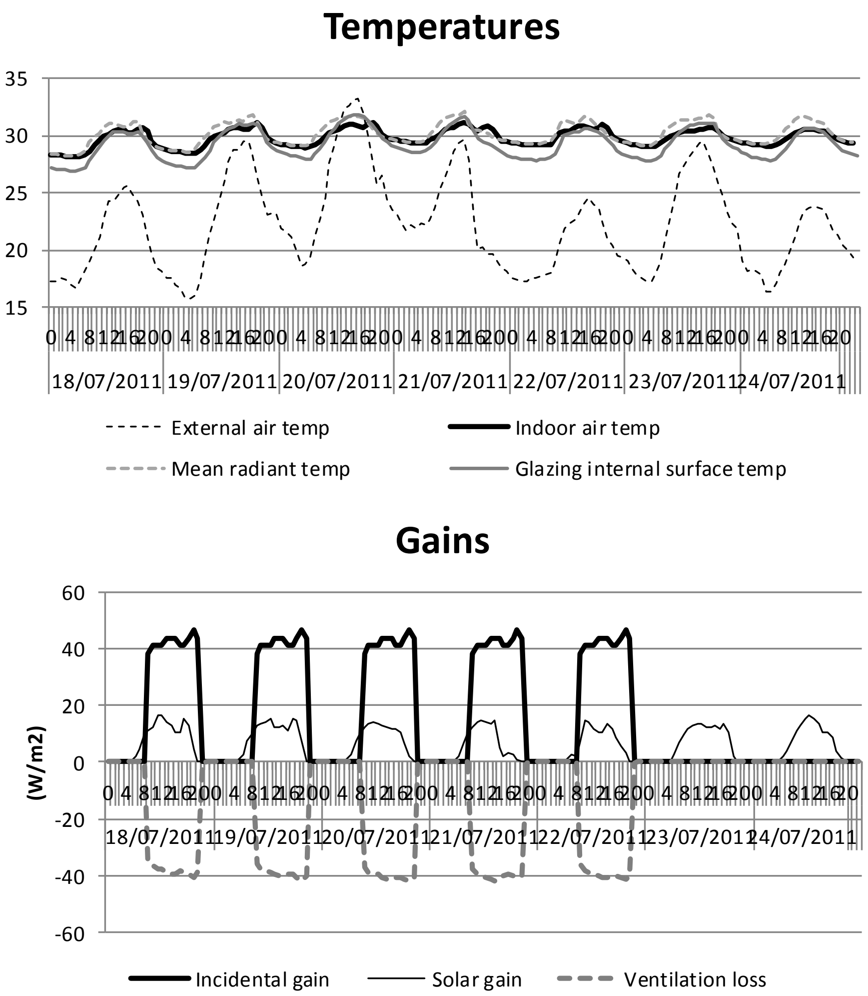

Figure 12: The internal temperatures and gains in the studied space from the dynamic simulation

The histogram of the operative temperature during the operation hours from 16th of April to 15th of October has been have been generated to show the distribution of hourly operative temperature (Figure 13).

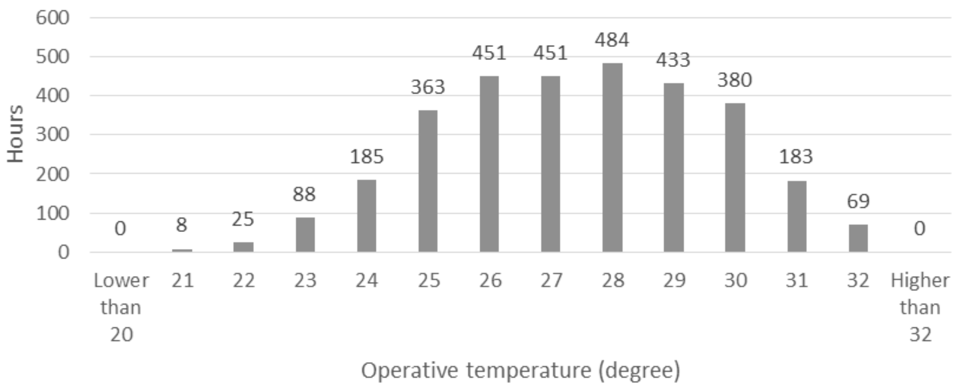

Figure 13: Histogram of operative temperature from 16/04 to 15/10 during operation hours

The dynamic simulation results were then analysed in relation to the SIA 180 standard. The analysis indicated that there are **2637** hours when the operative temperature is higher than the limit for mechanically ventilated space (Figure 14). Due to the high number of unmet hours, simple passive design strategies could not effectively reduce the unmet hours. It had been decided that cooling system would be applied.

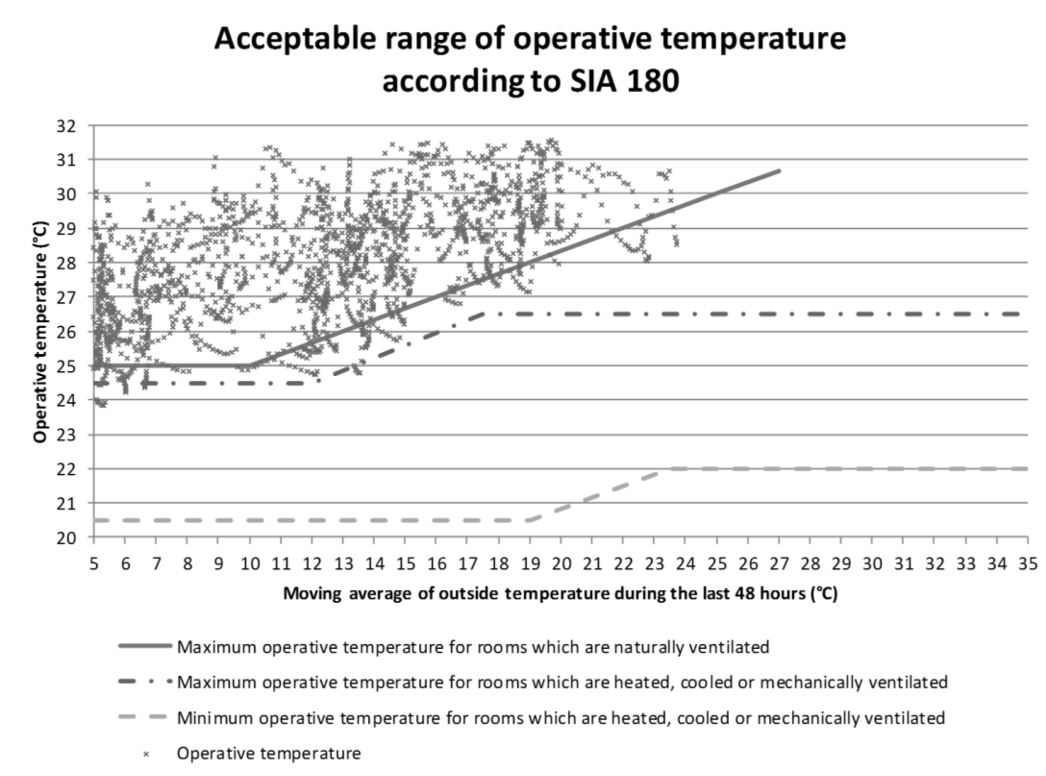

Figure 14: The compliance with the SIA 180 based on the dynamic simulation results

5 Discussion and conclusion:

This paper reviewed in detailed the systematic evaluation methods and associated criteria to evaluate thermal performance in both naturally ventilated space and mechanically serviced space in SIA 180:2014 and SIA 382/1 standards. It also shared our experience in using computer dynamic simulation to evaluate the designed thermal performance in order to ensure the compliance of both standards in practice. It suggested that computer simulation are required to be integrated into the mainstream design process to assist design teams in the compliance with the mandatory or volunteer low carbon standards. However, the evaluation methods and the software package need to be straight forward and easy to apply.

Thermal comfort is an important component for the design of low carbon buildings. First, to achieve and improve thermal comfort for the occupants is an aspect of low carbon design that cannot be overlooked. A series of models have been developed to predict thermal comfort to help the design teams deliver comfortable spaces for occupants. Second, thermal comfort standards have a significant impact on the overall energy consumption. de Dear and Brager (2002) claimed that energy saving could be achieved by changing from the traditional PMV–PPD based comfort standard to an adaptive comfort standard. Therefore, it is of importance to set up thermal comfort standards which reflect the requirement of occupants, as well as the energy consumption balance.

With the fast development of the construction industry in China, energy consumption has been the main focus. At the same time, it is of importance to explore how to improve the occupants' thermal comfort within the standard energy benchmark. A step further can be set up mandatory thermal comfort criteria which are tailored to be suitable for different climate zones in China and develop associated evaluation methods.

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