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Modeling the Air Temperature Profiles in the Cavity of a Double-skin Façade

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ABSTRACT

The paper addresses a modeling approach to reduce energy use for conditioning a double-skin façade cavity of an existing large pharmaceutical production facility featuring 10 structural levels. Upon an examination of the limits of available building energy software a decision was made towards developing a new computation program, which offers dynamic resolution of the building physics involved while also taking into account the intended control strategy of the fan-supported cavity ventilation. To obtain the full picture of the façade performance during the operation time (24 * 7), simulations were carried out for 10 main representative cases. On the basis of the overall analysis of the simulation results, a façade performance control strategy was found which allows for extensive energy savings during most parts of the year, although, as requested by building operator, the proposed measures do not involve any significant retrofitting of the production facility.

1. INTRODUCTION

Even though double-skin façades may use much more energy than conventional building structures, they are widely employed in all kinds of buildings, including production facilities. The recent resurgence of efficient building design has led to government policies constantly pushing for more energy efficient buildings and Green Building Councils rewarding points for reduction in energy consumption vs. a base case. This has caused a strong motivation among building operators to look for a strategy to optimize energy performance of the existing buildings.

2. DESCRIPTION OF FACILITY

The building to be optimised (Figure 1) is a ten-storey structure with double skin glass façade enveloping ca. 18000 m² of clean-room pharmaceutical production area. The production and administration rooms are situated between the central supply core and the façade. The building's façade is partly shaded by neighbouring buildings.

Several air-conditioning systems ensure that the indoor air conditions are met as required depending on the use of the rooms. The return-air concept of ventilating the bank of windows provides for pre-cooling in summer and serves as a kind of buffer in winter, preventing that the building cools down. It is a circumferential air flow design concept which ensures that the air blown into the double skin glass façade area is conveyed from the Southern façade to the East, North, and West, and eventually back to the South side from where it is returned to the air handling unit (Figure 2). To prevent short circuiting, the supply and exhaust air flows are separated by a glazed wall inside the façade that fills the whole cross section.

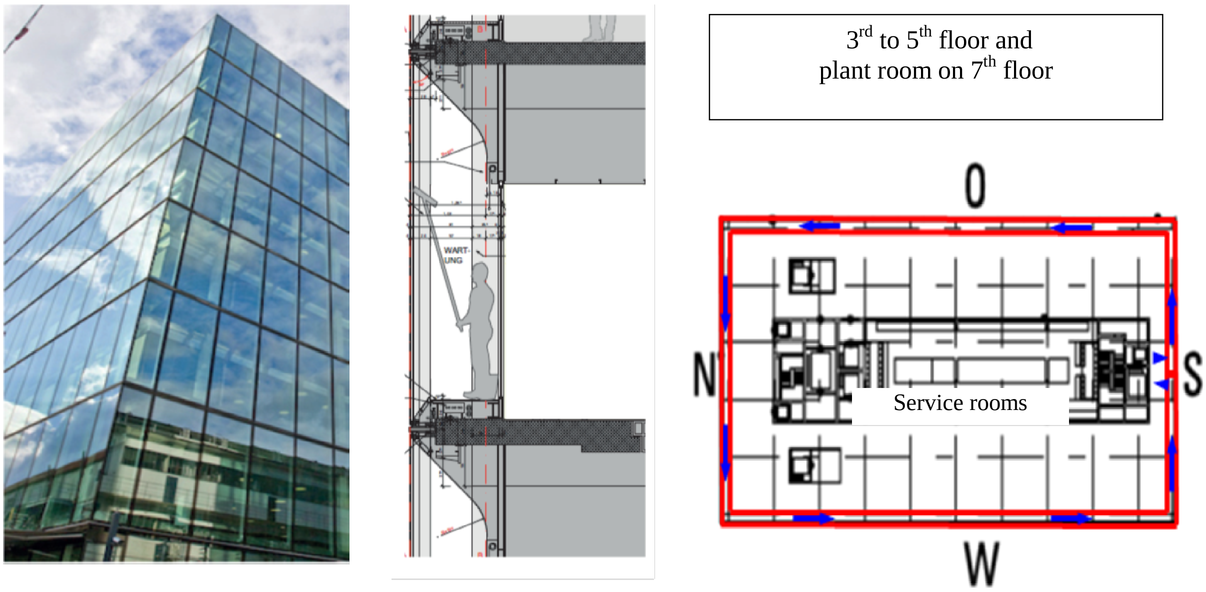

Figure 1: Production building analyzed

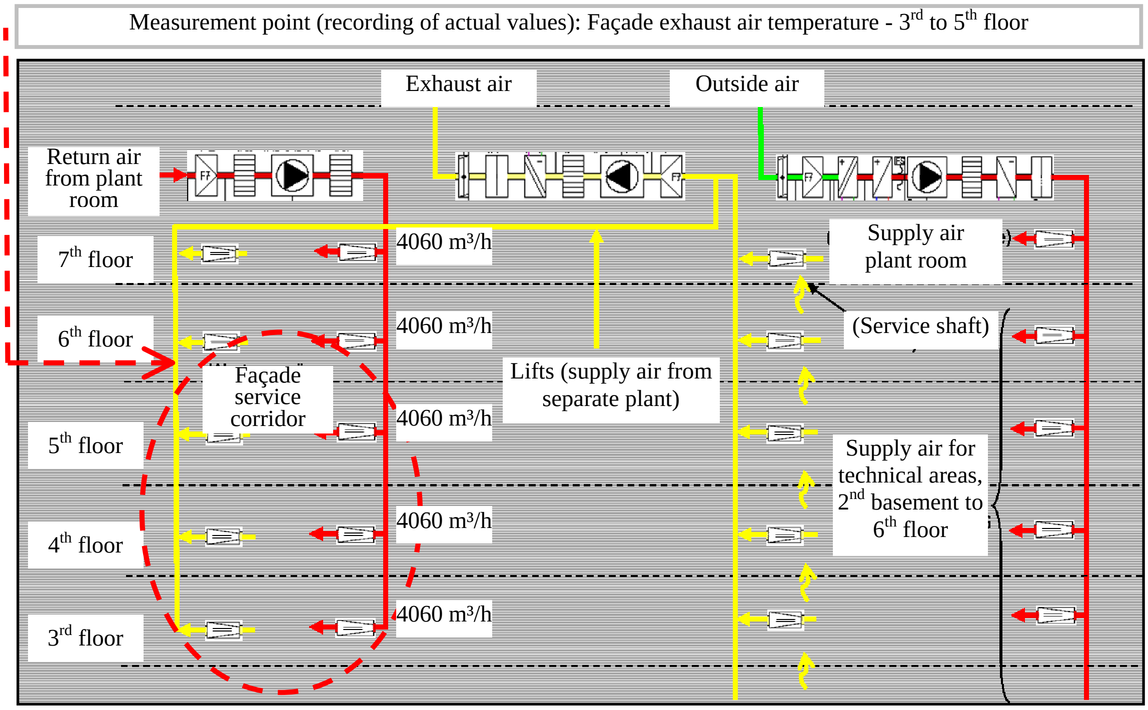

Figure 2: Air conditioning system

3. INFLUENCING FACTORS AND BASIC CONDITIONS

The most important points are, in the first place, the façade exhaust air temperature resulting from conditioning together with the pertaining façade supply air volume and related air conditions and, secondly, the outdoor and indoor temperatures. Special attention was given to the thermal comfort criteria since, highly sensitive products are produced and the highest degree of concentration is required from the staff.

A particular aspect of the simulation is the most realistic representation of the solar radiation conditions for the building. Hence, orientation and shading of the structure by neighbouring buildings play a significant role. Another important factor is the procedure applied to assign the radiation conditions to bright and dull days. To determine the exact conditions at the object the data material from VDI 2078 (VDI cooling load regulations) has been applied. Representing the surrounding buildings true to scale (Figure 3) allowed measuring of the solar altitude and azimuth angles that might occur during the whole year and within one day for each façade. Thereupon, the irradiation periods were determined for each façade under due consideration of the relevant shading aspects. That means, the total radiation values from VDI 2078 are applied only in cases where irradiation actually occurs.

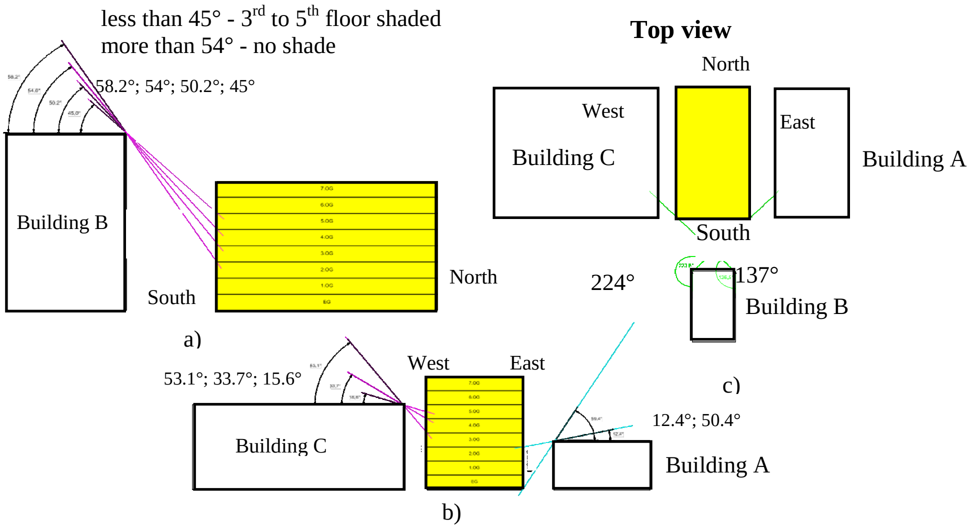

Figure 3: Surrounding buildings true to scale

4. DEVELOPMENT OF A COMPUTATION PROGRAM

Upon an examination of the limits of available building energy software a decision was made towards developing a new computation program (using the VBA-Code), which offers dynamic resolution of the building physics involved while also taking into account the intended control strategy of the fan-supported cavity ventilation.

The objective of the development first step was to prepare an excel-based simulation software program to shape the "ventilated double skin glass façade" part to the actual conditions considering the measured data recorded by STZ EURO. In order to find an appropriate depiction of the complex processes associated with solar insolation, shading, cavity divisions, vertical temperature gradient, etc., preliminary calculation results were verified against various measurement data collected in advance. Furthermore, an extensive sensitivity analysis was conducted in order to simplify the calculation routine for the "insensitive" façade sections. This allowed to keep the calculation time reasonable and still obtain an accurate prediction of the façade performance.

In a second step, the program was used to vary the system parameters in order to achieve operating conditions for the related air-conditioning system that offer better energy saving opportunities. Part of this simulation was an assessment of the impacts on the façade exhaust air temperature and on the temperature stratification in the double skin glass façade. Contrary to conventional dynamic simulation programs, such as TRNSYS, the impact resulting from adjustments to the circumferential ventilation parameters was in the focus here. Additionally, the shading impact caused by neighbouring buildings was analysed as precisely as possible for the object. Again, the measured data served to check the simulation quality.

5. COMPARISON OF SIMULATION RESULTS WITH ACTUAL CONDITIONS

After completion of the software programme's draft version a comparison with the actual conditions on the basis of the measured data is performed. In this connection it is noted that the simulation data feature a time delay when compared with the actually measured data. Such delay is caused by the neglected storage effect (Figure 4). After inclusion of a value for the constantly identical time delay into the programme there are hardly any deviations between simulated and actual conditions in the representation of the façade exhaust air temperature stratification (Figure 5).

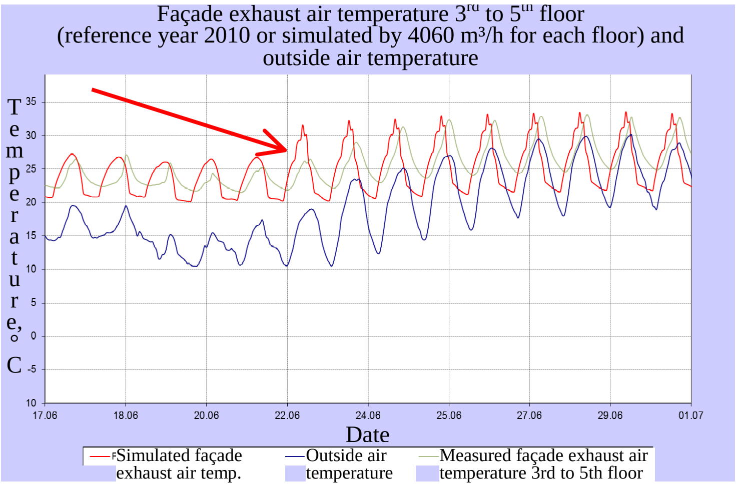

Figure 4: Deviation caused by neglected thermal storage effect

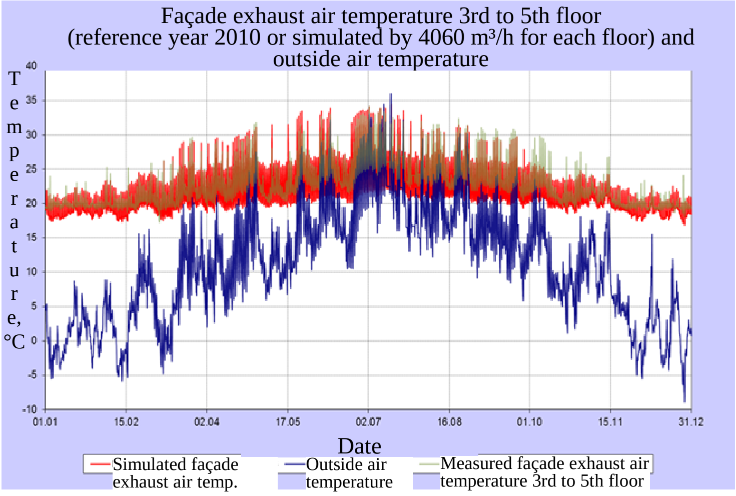

Figure 5: Satisfactory data correlation

As already mentioned before, thermal comfort criteria are also playing a significant role. Figure 6 shows examples of temperature stratification inside the façade at different times in summer and winter, respectively. Under the given ventilation conditions, the thermal comfort limits of category 1 are exceeded at the Eastern façade in summer from 10:00 to 14:00 hours. In winter, the temperature is slightly below the thermal comfort limits, however, at times when it is uncritical. Such state is deemed an acceptable reference in the simulation.

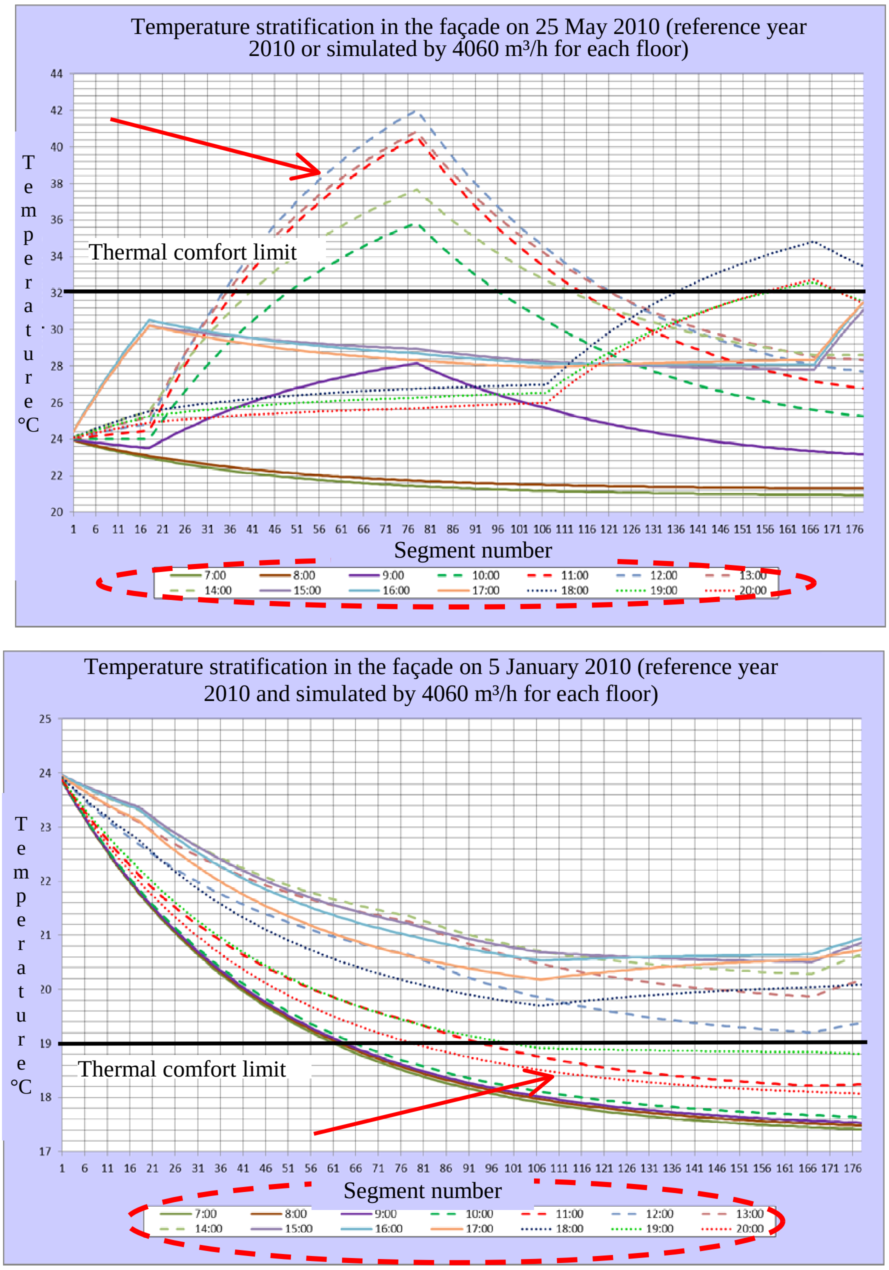

Figure 6: Temperature stratification inside the façade

6. SIMULATION OF VARIOUS OPERATION MODES AND ANALYSIS OF FINDINGS

To illustrate the opportunities offered by the simulation programme an overview is given in Table 1 listing the simulations performed for my bachelor thesis. The simulations mainly cover variations of the façade supply air volume and options for a switched-off return air system.

The daily temperature gradient diagrams shown in Figure 7 clearly demonstrate the impact of air volume reductions according to simulation options 1 to 7. As expected, such reductions have a greater impact in summer and more care should be dedicated to their implementation in summer than in winter.

Table 1: Simulation Options - Overview

No	Description	Flow Rate, m^3/h	Solar Radiation included
Options 1 – 3	**Reference year**: Actual condition (total year)	4.060	Yes
Option 4	Actual condition reduced by 25 % (total year)	3.045	Yes
Option 5	Actual condition reduced by 50 % (total year)	2.030	Yes
Option 6	Actual condition reduced by 75 % (total year)	1.015	Yes
Option 7	Return air system off (total year)	100	Yes
Option 8	Return air system off (Sep. to 15 March), other times – the same as reference	100/4.060	Yes
Option 9	Return air system off (total year)	100	No
Option 10	During the day – the same as reference / at night-time – return air system off (simulated for time from 15 March to 31 May)	4.060/100	Yes

To achieve energy savings while simultaneously maintaining the thermal comfort limit it is therefore advisable to adjust the air volume according to the season. Option 9 demonstrates the impact of solar radiation whereas options 8 and 10 already include initial suggestions for optimisation: summer/winter mode and day/night mode. Such operation modes offer considerable saving potentials without having any adverse effect on thermal comfort.

An overview on all simulation options is given in Figure 8.

As a result of the simulation options the following statements can be made:

- None of the air volume reduction options has an impact on the minimum façade exhaust air temperature or the temperature inside the façade.
- The lower the air volume the higher the number of hours beyond the thermal comfort level inside the façade.
- With the system being completely switched off in summer, the façade exhaust air temperature will be approx. 46 °C and the temperature inside the façade will reach approx. 48 °C.
- Option 8 mostly meets the reference values, i.e. it is unproblematic.
- When considering night-times only (option 9), it is possible to switch off the return air system completely.
- Once adjusted, the simulation represents the actual state in a satisfactorily exact way.
- The temperature increase beyond the thermal comfort limits inside the façade in summer is the more critical case. Thus, the winter case is unproblematic.
- The air volume during the night can be reduced over the whole year.
- The air volume during the day can be reduced in winter (September to March).
- The thermal comfort conditions of the actual state are met in both cases of air volume reduction.
- If the return air system is completely switched off in winter (4.704 h) and during the nights in summer (1.521 h) savings of 6.225 hours of fan operation could be achieved in total (corresponding to 71 % of the fan operation hours during one year).

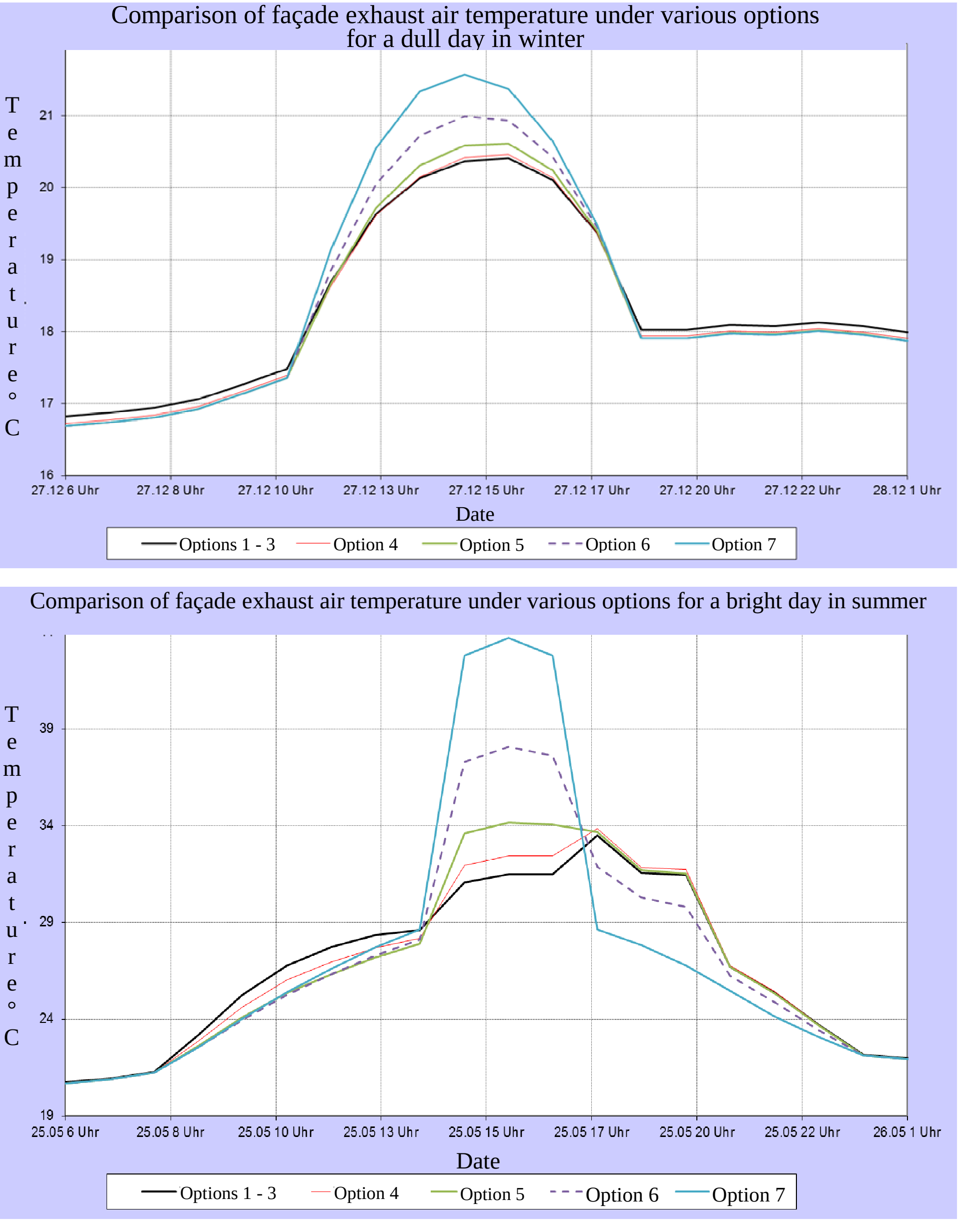

Figure 7: Daily temperature gradient diagrams
a) Coldest day of the year, down to -8.9°C (winter case)
b) Day with max. solar radiation (summer case)

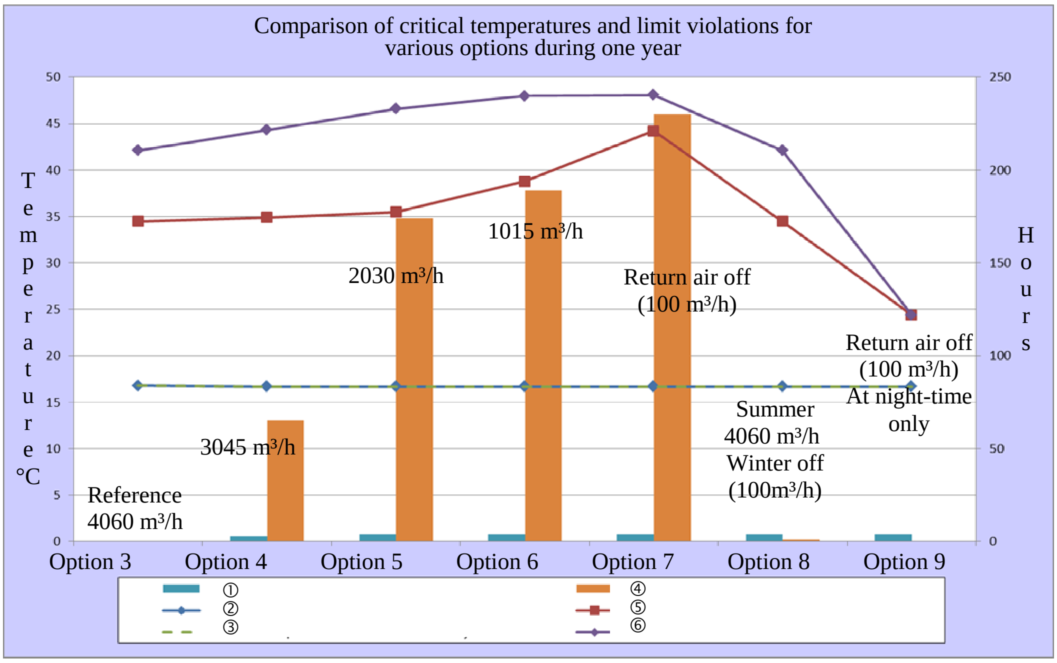

Figure 8: Simulation options overview
① - Number of hours per year when the temperature is lower
② - Minimum façade exhaust air temperature during the year
③ - Minimum temperature in the façade during the year
④ - Number of hours per year when the temperature is higher
⑤ - Maximum façade exhaust air temperature during the year
⑥ - Maximum temperature in the façade during the year

7. CONCLUSION

The overall analysis showed that extensive savings are attainable for most parts of the year, even though, as requested by building operator, the proposed measures do not involve any significant retrofitting of the production facility.