APPLICATION OF COMPLEX ENERGY SIMULATION IN COMPETITION DESIGN OF CZECH EMBASSY IN OTTAWA

Karel Kabele, Magda Kadlecová, Tomáš Matoušovic, Lada Centnerová
Czech Technical University in Prague
Faculty of Civil Engineering, Department of Building Services Engineering
Thákurova 7
166 29 Praha 6, Czech Republic
e-mail:kabele@fsv.cvut.cz

ABSTRACT

This paper describes use of building energy performance modelling and simulation in design process at the early conceptual level of architectural design. Based on the architect's initial ideas, four alternatives of building facade solution and air-conditioning system operation were developed and simulated in real climate conditions, represented by typical winter and typical summer week. Results in terms of heating and cooling energy consumption and flux and air temperature in the double facade cavity course are discussed, and a recommendation for further design process is made.

INTRODUCTION

In Czech republic, computer modelling and simulation of energy performance and indoor environment is usually not used at conceptual level of architectural design process of standard buildings. Current design practice is such that, an expert for energy use and environmental control is invited to participate in the design process in the phase, when the building shape and structure is almost fixed. All recommendations given by the expert, based on an energy and environmental performance analysis, are implemented into the almost designed building. The implementation is often very inefficient or expensive due to the impossibility to make major changes in the building philosophy. In the case, which is subject of this paper, there was a very good co-operation between the architect and the specialist for building energy performance simulation. This could be an example of a new approach to architectural design process. We hope that this case will help to answer the usual architect's question - "In which phase of architectural design it is time to carry out energy simulation and what can I expect from it?" The co-operation between the architect and the building energy specialist in this case started already in the phase of the conceptual solution of the building. In this phase, an energy and environmental analysis of various building concepts was carried out.

PROBLEM DESCRIPTION

Three alternatives of the building concept were proposed. All solved alternatives had the same boundary conditions, given by the rules of the architectural competition: resulting shape of the building had to be a block, facade had to have an appearance of glass walls. Inside space had to be divided into two two-storey multipurpose office spaces connected with atrium (Fig.1).

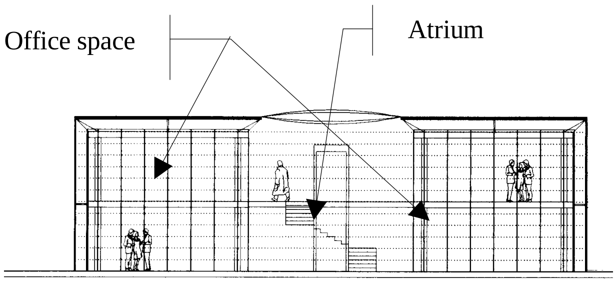


Fig. 1 Architectural design of building

The objective of the analysis was to find a solution, which minimises energy consumption for cooling and heating of the building, while fulfilling all comfort criteria. It was also necessary to address the question of sick building syndrome, which can be caused, among others, by the full centrally controlled air-conditioning with no possibility of individual control. All the alternatives were subjected to complex energy and environmental simulation, their energy consumption and indoor environment quality were compared and the optimal solution was selected.

Alternative 0

The "zero" – reference alternative was the traditional solution of this type of building - simple glass "cube" with double-glazing, with non-openable windows and full air-conditioning of the space.

Alternative 1 (Fig. 2)

The first analysed alternative was aimed at describing the influence of active sun blinds on windows, which are automatically closed at solar radiation 400 W.m^{-2} – this value was also the subject of investigation.

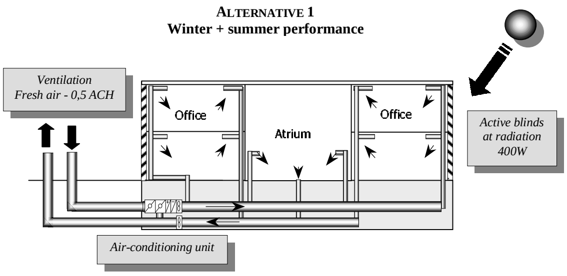


Fig. 2 Alternative 1

Alternative 2 (Fig. 3, Fig. 4)

The second alternative was designed as building with doubled glazed facade with "passive" air cavity, which is closed in a winter season, and opened into the outside environment in a summer season. On the outer glazing of the facade, automatic active sunblinds were installed, as in alternative 1. The windows were not openable and the space was fully air-conditioned.

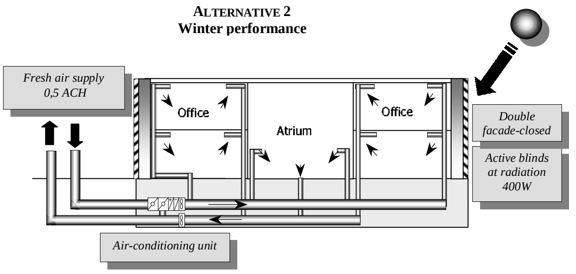


Fig. 3 Alternative 2 – winter performance

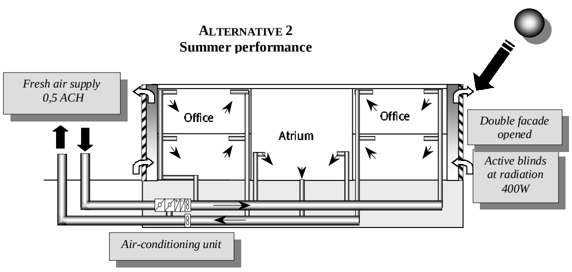


Fig. 4 Alternative 2 – summer performance

Alternative 3 (Fig. 5,Fig. 6)

The third alternative of the building operation and construction solution was a solution with maximum implementation of low-energy building elements. A specific problem of the present building was that, according to architectural competition rules, there was a request for equal appearance of all facades - full glazing. The principle of the double skin facade with active cavity, which is used as a part of the building ventilating system, was employed.

The initial idea of alternative 3 was to ventilate office rooms directly from facade cavity by openable windows. Later, a new solution was accepted, based on temperature in facade cavities obtained by a simulation. Particularly in summer period was air temperature in the cavity high and increased heat load. The new solution was that, the cavity is supplied by fresh air, which is preheated (pre-cooled) in an earth heat exchanger and heat recovery system. In winter, this air is used as a supply for air-conditioning of office rooms. During summer period, the hot air from the facade cavity is ventilated to the outdoor environment and the office rooms are supplied directly from air-conditioning system.

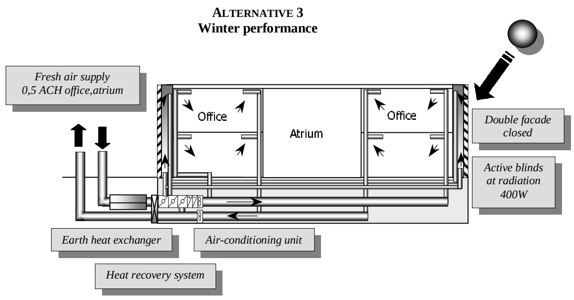


Fig. 5 Alternative 3 – winter performance

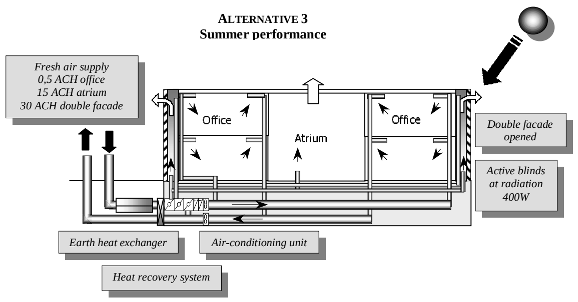


Fig. 6 Alternative 3 – summer performance

MODELLING

Computer program ESP-r (ESRU 1996) was used as the modelling and simulation environment.

The building

The building model comprises five thermal zones representing the main body of the office spaces and atrium. The air cavities, created by double facade, were represented by six thermal zones, adjacent to the office zones (Fig. 7). This allowed us to investigate and monitor temperature profiles in the double facade cavities according to cardinal points.

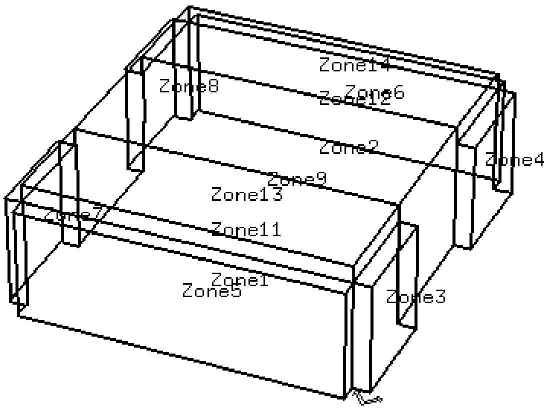


Fig. 7 ESP-r model of the building

The air-conditioning system

The air-conditioning system operation was included into the model. A fresh air exchange of 0.5 ACH was prescribed in all office rooms, in order to fulfil hygiene requirements. In the task formulation, there was no request on lowest air temperature in the atrium during the winter period and no special request on maximal air temperature in the atrium during summer period. Due to the reduction of heat gains from atrium to the adjacent office rooms there was only designed to ventilate the atrium 5ACH during summer period using the air pre-cooled in the earth heat exchanger to 15°C with no additional cooling energy supply. The 5 ACH was assumed to be constant.

Modelling of air exchange in the double facade cavity was solved in terms of air volume and temperature (Tab. 1, Tab. 2).

Winter performance of air cavity in facade				
Alternative.	Supply		Outlet	
	ACH	From	ACH	To
II.	0		0	
III.	1	earth exchanger	1	office zones

Tab. 1 Winter performance model of air cavity exchange

Summer performance of air cavity in facade				
Alternative.	Supply		Outlet	
	ACH	From	ACH	To
II.	300	outdoor	300	outdoor
III.	30	earth exchanger	30	outdoor

Tab. 2 Summer performance model of air cavity exchange

At this level of conceptual study, the earth heat exchanger and heat recovery system was not solved in detail. Requirements on these devices were included in the model by considering constant air temperature on outlet from the heat recovery system. In the winter period, it was +5°C, in summer +15°C.

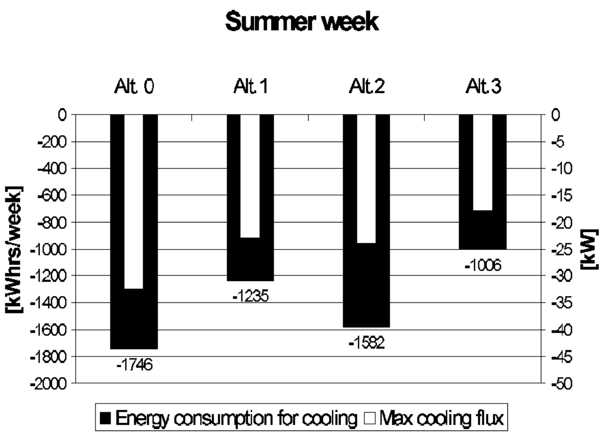
SIMULATION AND RESULTS

Two critical periods were selected using Ottawa (Canada) climate files. Typical winter week with outdoor air temperature amplitude <-25;-12°C> and typical summer week with outdoor air temperature amplitude <+18;+32°C>. Integrated building simulation was used, with time step 1 hour and initial period 16 days. During simulation, no major problems were detected by the program, local short-time overheating in several double facade zones were tuned by setting the blind control to 400 W/m^2 and air exchange volume, as described above.

The discussion of results was focused on heating/cooling energy consumption, heating/cooling energy flux and temperatures in double facade cavities.

Energy consumption (Tab. 3)

Fig. 8 Cooling energy consumption and flux



a) Summer (Fig.8)

Comparing solved alternatives according to the summer cooling energy consumption, there is a remarkable difference between all alternatives. In the alternative 1, installation of controlled blinds caused energy consumption decrease of 29%, comparing to the reference 0-alternative. The increase of cooling energy consumption in alternative 2 is caused by the additional facade and placing the blinds to the internal side of double facade outside glazing, which decreases heat losses.

Alternative 3 exhibits the lowest energy consumption due to utilisation of earth heat exchanger and heat recovery system.

b) Winter (Fig.9)

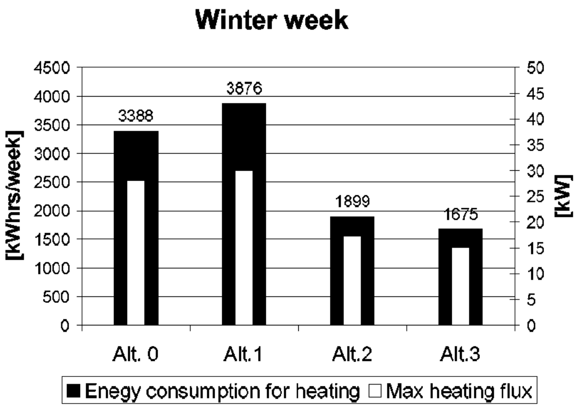


Fig.9 Heating energy consumption and flux

Installation of active blinds in alternative 1 reduced the heat gains not only in summer, but also in winter.

	Cooling	Heating
Alt.0	100%	100%
Alt.1	71%	114%
Alt.2	91%	56%
Alt.3	58%	49%

Tab. 3 Energy consumption (Alt. 0 =100%)

This is the main reason of heating energy consumption increase. Installation of double facade (alt.2 and alt.3) is undisputedly positive step in heating energy reduction process.

Energy flux(Tab.4)

a) Summer (Fig.10)

Similarly with the energy consumption, there is a remarkable positive influence of active blinds in Alt.1 and a slightly negative influence of double facade in alternative 2. Again, the alternative 3 is the best, reducing cooling flux to 55% compared to alternative 0.

b) Winter (Fig.11)

In terms of heating flux, the alternative 1 is the worst due to the reduction of solar gains with no improvement of thermal properties of the building envelope.

	Cooling	Heating
Alt.0	100%	100%
Alt.1	71%	107%
Alt.2	74%	62%
Alt.3	55%	54%

Tab. 4 Energy flux – output of the plant (Alt. 0 =100%)

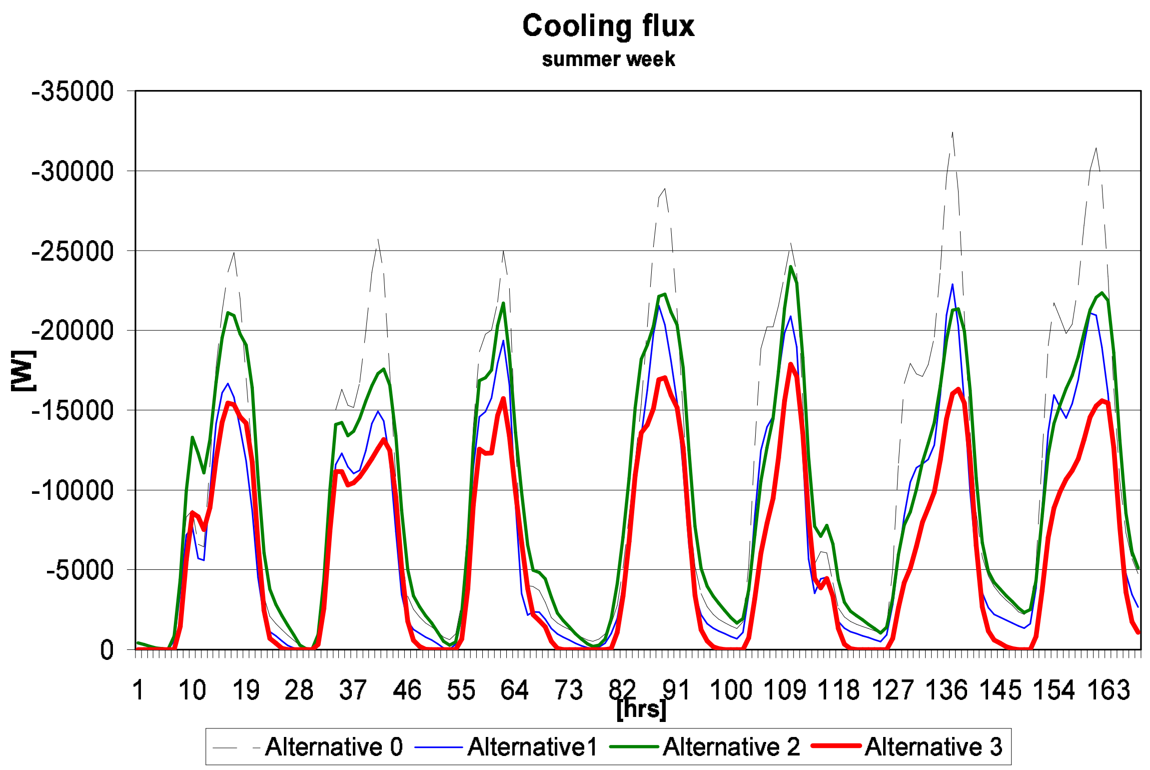


Fig. 10 Cooling flux

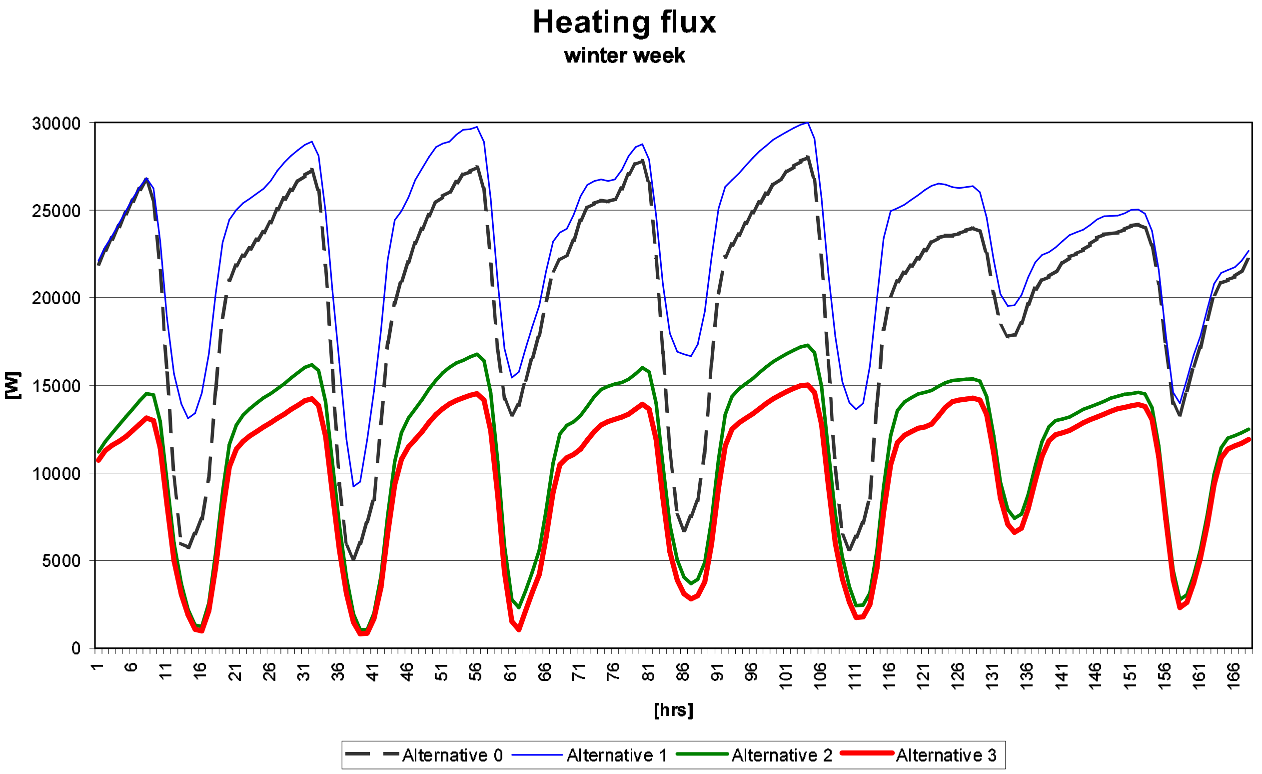


Fig. 11 Heating flux

In one can see this effect during sunny winter days (e.g. between hour 82 and 86). In alternatives 2 and 3, there is a remarkable influence of double facade air cavity, which is closed in the alternative 2 and ventilated by preheated air from earth heat exchanger in alternative 3.

Temperatures in double facade cavities

The temperature in double facade cavities was limited by technical requirements to maximum of 40°C. Critical for this limit is alternative 2 with "passive" air cavity, which should be opened during summer period. The designer's question was as "what volume of air should we change in the cavity to keep the temperature below maximal value?". This problem was solved on zone 5, which is oriented to the south and during simulation exhibited the highest temperatures. Air exchanges in the double facade cavities were theoretically varied in the range from 25 to 300 ACH. Effect of changing this variable on maximal air temperature, cooling flux and total cooling energy consumption was observed. Temperature limit of 40°C was exceeded at 25 ACH. The minimal air exchange fulfilling this condition was 50 ACH (Fig.12).

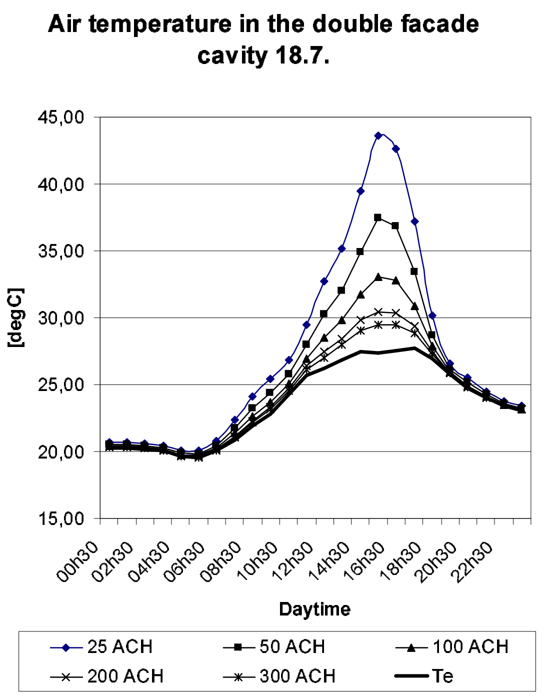


Fig. 12 Relation between the air temperature and air exchange in the double facade cavity

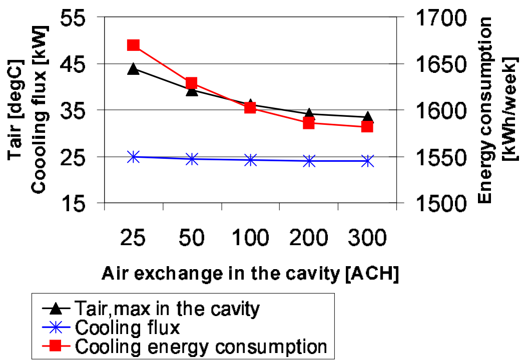


Fig. 13 Relation between air exchange in the cavity and tai max, cooling flux and cooling energy consumption.

There is essentially no effect of air exchange variation to maximal cooling flux, which is given mainly by solar radiation (Fig.13). On the contrary, there is a relatively significant relation between air exchange variation and total cooling energy consumption in the observed range. Major relative drop is in the range 25ACH to 200 ACH; further increasing of air exchange volume is not so efficient.

ACH and volume of the cavity give air volume, which is necessary to exchange in the air cavity. In our case, when the volume of monitored cavity is approximately 40 m^3, the air exchange volume at 50ACH is 2000 m^3h^{-1} at average air velocity in the cavity 4,5 $m.sec^{-1}$. This airflow would be difficult to obtain by natural ventilation, so there will be necessary use of fans and the energy used for them should be included into the evaluation of this system.

CONCLUSIONS

The major purpose of this study was to prepare information for an architect's conceptual decision. All numerical results are related to the reference alternative solution.

Cooling energy consumption and flux

In terms of cooling energy consumption, alternative 3, with air, pre-cooled in earth exchanger delivered into the double facade cavity, is the best. However, the condition for fulfilling this positive result is such design of earth heat exchanger and heat recovery system, which ensures the supply air temperature to be +15°C with no additional cooling. Contrary to initial assumption, natural ventilation of double facade cavity in combination with blinds on external glass of the facade (alternative 2) did not bring the expected results, and cooling energy consumption remained on very high level (91% of reference alternative). Due to the time restrictions we did not check the influence of the changing the blinds location on to the exterior of internal glazing, which could decrease heat gains. This will be subject of our future investigation.

Heating energy consumption and flux

In terms of heating energy consumption, alternative 3 with earth heat exchanger and heat recovery system is the best. There is no significant difference between alternatives 2 and 3. Increase of energy consumption and flux in alternative 1 is due to installation of blinds, which are reducing solar gains in winter period.

Temperatures in the double facade cavity

As it was mentioned above, the highest temperature in the cavity was limited to 40°C and the problem of overheating of the cavity occurs only in alternative 2. To avoid the overheating, the minimal designed air exchange in the cavity has to be in the range 50-200 ACH.

General conclusion

In terms of the solved problem:

For the solved building and climate conditions we recommend to use Alternative 2. Even though the results in terms of energy consumption and flux are slightly better for the alternative 3, known problems with maintenance and operation of earth heat exchangers make alternative 3 less preferable.

It is recommended to focus on summer period to reduce heat gains in alternative 2

In terms of the used method:

Co-operation between architect and building energy specialist resulted into the design, based on building energy performance simulation. Major problem of entire task was to find “common language” to transfer architect's complex ideas about building alternatives into the model and select, which results are most important. ESP-r environment showed at this case its power in wide range of results , what could be demonstrated on example of air exchange in the facade cavity tuning, which would be difficult to solve by other, non-complex computer programs.

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