

Simulation to support passive and low energy cooling system design in the Czech Republic

Citation for published version (APA):

Lain, M., Bartak, M., Drkal, F., & Hensen, J. L. M. (2005). Simulation to support passive and low energy cooling system design in the Czech Republic. In *Proc. Int. Solar Renewable Energy News SREN 2005 Conference, 2 - 8 April, Firenze, Institute of Physics SAS, Bratislava* (pp. 1-25).

Document status and date:

Published: 01/01/2005

Document Version:

Accepted manuscript including changes made at the peer-review stage

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Simulation to Support Passive and Low Energy Cooling System Design in the Czech Republic.

M. Lain, M. Barták, F. Drkal, J. Hensen*

Department of Environmental Engineering, Faculty of Mechanical Engineering, Czech Technical University in Prague, Czech Republic.

**Center for Building & Systems TNO-TU/e, Technische Universiteit Eindhoven, Netherlands.*

This paper deals with the passive and low energy cooling technologies in the Czech Republic. The role of computer simulation in low energy building design and optimization is discussed. The work includes buildings and systems analysis as well as climate analysis in order to estimate the potential of passive and low energy cooling technologies. The former is based on case studies, which include both building simulation and monitoring.

Computer simulation, low-energy cooling, air-conditioning, HVAC system, Building, Czech Republic,

1 INTRODUCTION

Buildings consume approximately 40 to 50% of primary energy in European countries. Energy consumption for cooling represents approximately 10 % of the total consumption for commercial office buildings. The percentage of fully air-conditioned office floor area is increasing in Europe, especially in the Czech Republic, where full air conditioning is the current de facto standard in new or reconstructed office buildings. The increasing use of information technology has led to an increasing demand for cooling in commercial buildings. Cooling thus accounts for a significant proportion of the total energy consumption in buildings, and its impact on greenhouse gas emissions is enhanced by the fact that these cooling systems are usually electrically driven and electricity in the Czech Republic is mostly produced by coal power plants (Santamouris 1996, Heap 2001).

1

of cooling; whether it is ambient air or ground temperatures or warmer chilled water. Those technologies may be considered passive and hybrid cooling systems. (The term passive cooling should not be confused with passive cooling building design which is focused on reducing the cooling load).

Low energy cooling technologies can be divided into two groups: those including the main source of cooling and those that focus solely on delivery of cooling to the treated space (IEA 1995, Liddament 2000).

The first group of systems rely on natural sources of cooling, but fans or pumps are required for most of them. Examples of such technologies are:

- ☞ Night ventilation
- ☞ Evaporative cooling
- ☞ Ground cooling

The second group of technologies focus on delivering the cooling to the treated space in an efficient manner, those technologies usually work well with lower grade sources of cooling.

2 CLIMATE IN THE CZECH REPUBLIC

The Czech Republic is an inland country located in the middle of Europe. The capital and also the biggest city is Prague. Most governmental and business offices are located there. The Czech climate can be described as warm (summer peak design temperature 32°C) and semi-humid (summer design moisture content 10 g/kg and wet bulb depression 9 K).

When comparing the Prague climate to other cities, where some low-energy cooling studies have been carried out, it was found that the summer climate is very similar to Berlin (Figure 2). Therefore the Berlin summer results and experiences can be used for preliminary studies for Prague.

For evaporative systems enthalpy hours are defined which take into account the humidity of the air (IEA 1995). The cooling degree hours (CDH) and enthalpy hours (EH) were calculated twice, using two different reference temperatures, namely 18°C (index 18) and 25°C (index 25). The reference

3

Many buildings are still constructed or remodeled without consideration of energy conserving strategies or other sustainability aspects. To provide substantial improvements in energy consumption and comfort levels, there is a need to treat buildings as complete optimized entities not as the sum of a number of separately optimized components.

Simulation is ideal for this because it is not restricted to the building structure itself but can include the indoor environment, while simultaneously taking into account the outdoor environment, mechanical, electrical or structural systems, and traditional and renewable energy supply systems. By assessing equipment and system integration ideas, it can aid building analysis and design in order to achieve a good indoor environment in a sustainable manner, and in that sense to care for people now and in the future.

The use of computer modeling and simulation for the design and/ or evaluation of buildings and HVAC is quickly moving from the research and development stage into everyday engineering practice. In contrast to the traditional simplified calculating methods (not considering the system dynamics), computer based modeling approaches reality much closer (Figure1).

Computer simulations are demanding more input information and data processing than ordinary design work. On the other hand, once the model is prepared, simulation techniques allow quick and detailed analysis of various solutions for the building geometry and construction as well as for the design and operation of HVAC systems. The aim of computer modeling is to optimize the design of a building and its service system according to the requirements for indoor air quality while keeping energy consumption at minimum levels.

The presented case studies serve both to illustrate the current state of the art in the Czech Republic, and to illustrate different options for energy conservation, especially low energy cooling.

1.1 LOW ENERGY AND PASSIVE COOLING TECHNOLOGIES

Low energy cooling technologies provide cooling in an energy efficient manner, thus reducing energy consumption and peak electricity demand. They do so by making use of low quality sources

2

relative humidity for calculating enthalpy hours was 40%. Enthalpy hours and cooling degree hours for Prague are compared to some other towns in Table 1.

3 RETROFIT OF HISTORICAL BUILDINGS

These are characterized by massive construction (brick, concrete), a window area up to 30% of the facade, and were build up to the 1950-ies.

These buildings are usually not air-conditioned, nor mechanically ventilated. Retrofit of such buildings is always individual. Most heavy historical buildings can be operated without air-conditioning. High thermal mass helps to maintain thermal comfort as long as passive cooling rules (low internal gains, shading) are obeyed during retrofit. The thermal mass of the building can guarantee comfort requirements.

4 ART GALLERY IN SOVOVY MLYNY

One of the main disadvantages of traditional engineering design methods for HVAC systems is the underestimation of the impact of thermal accumulation of the building structure. Neither periodic changes in outdoor air temperatures nor the influence of building structures can be fully considered in the traditional approach. This often leads to oversized heating and cooling system components, particularly in the case of historical buildings usually with very heavy constructions.

To support the design process of a new art gallery to be housed in the historical Sovovy mlyny building in Prague, computer simulations were used to predict the required cooling capacity of the air-conditioning system. According to the standard design method, the cooling capacity was estimated at 100 kW. The cooling system components should have been sized to this value and the ventilation ducts would have to be designed to transport such a big cooling load. However, only minimum changes to the construction and to the historical interior appearance would be allowed; e.g. no extensive ductwork and the like.

4

The future art gallery will be situated on the 1st and 2nd floor in the building's north wing. This part is built with heavy external masonry walls (80 cm thick) and the windows are equipped with internal wooden shutters. Thus the interior is actually well sheltered from solar heat gains and the building structure is also capable of significant thermal accumulation. A 3D model, with six thermal zones, was generated representing the relevant part of the building (see Figure 3).

The dynamic performance of the building was simulated with ESP-r taking into account the influence of the building structure, shading by surrounding buildings, interior operation (heat gains from occupants and lights) and extreme summer conditions in Prague represented by one-week real weather data measured in August 1997. The model was calibrated on the basis of air temperature measurements performed in the existing building.

The indoor thermal environment was analysed for the case of when the building is ventilated by external air with optional cooling. The results showed a significant influence of internal heat gains from occupancy and lights. It was concluded that air-conditioning is necessary, but a total cooling capacity of only 25 kW could remove both the solar and internal heat gains while maintaining indoor air temperatures at 26°C or less. The total air volume flow rate would not be more than 6,000 m³/hour, which means small-sized ventilation ducts.

Figure 4 gives an example of indoor air temperatures in the building ventilated by external air without cooling. The internal sensible heat gains were assumed 15 W/m² from lights, plus 6.4 W/m² from occupants.

Figure 5 illustrates the optimised operating mode of the air-conditioning system. The gallery is continuously ventilated by external air; the cooling plant operates only when external air temperatures exceed the required supply air temperature (calculated on the basis of total heat gains in the gallery space).

The study helped not only to lower the investment costs to a significant extent but most of all to minimize the possible changes in construction and appearance of a valuable historical building.

5

grid into more than 1,895,000 control volumes. Boundary conditions in terms of internal surface temperatures were transferred from the results of the zone-based ESP-r simulations.

Two cases were considered: with open or closed roof windows, yielding two modes of indoor airflow. While the former causes a stable vertical gradient of air temperature (Figure 10) and natural ventilation with an acceptable rate of approx. 1 ACH, the latter makes the air temperature distribution uniform because of significantly circulating air flow. The energy and air-flow simulations showed that the building can serve as a concert hall for up to 300 visitors while the internal environment can be maintained by natural ventilation and (in winter) by heating of the seats. In the winter period (which is seen to be a critical part of the year) the internal air temperatures in the roof space would be quite stable and not far from outdoor conditions while the risk of moisture condensation on the walls is reasonably low. Indoor air velocities in occupied part should not exceed 0.4 m/s, which is favorable both for the visitors and the construction parts of the former church.

The building retrofit was finished atom 2004 and the indoor climate is monitored.

6 1950-1980 OFFICE BUILDINGS RTROFIT

These were build during the socialistic period and typically have a heavy concrete frame and floors and light prefabricated envelope, windows up to 60% of the facade. Neither air-conditioning nor mechanical ventilation was standard. A very high percentage of current Czech stock of office buildings falls into this category. Retrofit of this type is an actual problem. This is the subject of an extensive study using computer simulation (Lain 2004). Applicability of night ventilation and cooled ceiling panels was assessed in the study.

6.1 MODEL DESCRIPTION

Simulations were carried out for a typical office of 4.92 by 5.5 m with a room height of 3.2 m. There are two south-east facing windows resulting in 55% glazing of one of the walls. The model of the office is shown in Figure 9. As indicated, the office model consist of two thermal zones (with

7

5 CONCERT HALL IN THE FORMER CHURCH OF SAINT ANNA

Restoration of historical buildings and their adaptation to a different way of use introduces questions about the changes in internal operations and their influence on the building structures. This type of problem occurred also during the conversion of the former St. Anna church in the Old Town of Prague into a concert hall. The design team was concerned about indoor airflows, air temperature and humidity distribution, and possible moisture condensation on the internal wall surfaces. At the same time only natural ventilation through window openings at street level and roof windows was possible in order to preserve the original look of the building.

In this case a zonal method was applied for coupled energy and airflow simulations. A 3D model for ESP-r was generated, with 8 thermal zones, taking into account shading objects and adjacent buildings (Figure 6).

The former church itself is basically one large enclosure, which was subdivided into 5 fictitious thermal zones with a nodal airflow network (see Figure 7 where the fictitious surfaces are indicated by dashed lines). The simulation predicted air and surface temperatures as well as air flow rates due to natural ventilation.

Figure 8 shows time variations of surface temperature and dew point temperature in the winter period. It is obvious that the occurrence of moisture condensation on internal walls is very rare (i.e. only when the surface temperature is lower than the dew point temperature).

Figure 9 gives time variations of air temperatures in the building and outdoor environment. While the ground floor part of the concert hall would be strongly influenced by visitors and heating of seats (used in winter), the remaining space shows a good thermal stability. This is particularly important for the ancient wooden roof trusses.

A detailed investigation of indoor air velocities and temperatures distribution was performed using the Fluent CFD software. The building interior (approx. 9,630 m³) was divided by an unstructured

6

uniform air temperature) representing the "office zone" and the "cooled ceiling zone". Internal heat gains representing three occupants (3 x 62 W) each with PC (3 x 40 W) and monitor (3 x 58 W) are incorporated in the model.

6.2 SIMULATION AND RESULTS

Two passive cooling methods for improving thermal comfort in the not air- conditioned office in the summer were tested: decreasing the solar heat gains by shading or reflection and natural ventilation strategies.

The simulations were carried out for three ventilation strategies:

- V1 only infiltration - air exchange rate 0,5 h⁻¹; for 24 hours a day
- V2 night ventilation - air exchange rate 5 h⁻¹; from 18:00 to 7:00
- V3 daytime ventilation - air exchange rate 10 h⁻¹, from 7:00 to 18:00

Three types of glazing were simulated.

- S1 Standard double glazing with solar factor 0,71
- S2 Antisun bronze glazing with solar factor 0,48
- S3 Glazing with internal blinds, solar factor 0,2

All cases have been simulated without slab cooling (C0) and with slab cooling (C1), the cooling layer temperature was set to 17 °C for 24 hours a day, 7 days a week. This makes 18 combinations.

The simulations were carried out for three summer months, using a weather test reference year (hourly data) for Prague.

Some of results for a selected period of two weeks are presented in Figure 11 and 12. The 3 months results are summarized in the Table 2.

7 CONCLUSION

According to the simulation results all three low energy cooling strategies help to improve the indoor thermal comfort in the office. It is recommended to use antisun glazing with blinds especially if there

8

is not other cooling technology. The operative temperature was decreased by 10 K if just infiltration was used (Figure 11. left) and by 5 K for night ventilation (Figure 12. left). The natural ventilation has even a bigger effect on the inside temperatures; this is due to the fact that in our simulation very high air exchange rates have been selected. In reality it is difficult to reach such values and there are other practical problems with such intensive natural ventilation (safety, draft etc.).

The ceiling cooling was approved as system which only one can fully guarantee thermal comfort in the office. The effect of ceiling cooling was much stronger than other considered technologies. The simulation results even show occasional overcooling of the office. The question of the optimal ceiling (cooling water) temperature and the control of the slab cooling system remain for future research.

8 NIGHT VENTILATION

There is a high potential for night ventilation in the Czech Republic. As can be seen in Figure 13, the difference between maximum day temperature and minimum night temperature is usually more than 10 K. (The mean daily temperature range is 11.6 K). Also, the minimum night air temperatures are well below 18°C.

Not only night ventilation but also daytime ventilation can be used for cooling purposes in the Czech Republic. During 93% of the cooling season the outside air temperature is below 24°C. For working hours this is 94 percent.

9 OFFICE BUILDING WITH TOP COOLING

This case study deals with the use of computer simulations both for design support of a new building including its heating, ventilation and air-conditioning (HVAC) systems and for optimization of the HVAC control strategy during operation of the completed building.

9

is no individual control in the rooms nor on the floors. The system is operated 24 hours per day with a constant set-point of 24 °C. The temperature is allowed to drift up to 2 K during normal conditions and up to 4 K during extreme summer periods.

9.2 EARLY DESIGN SIMULATIONS

In the early design phases of the building computer simulations were carried out to prove the concept of night cooling ventilation and to study some other effects.

A section (2,5x15,5x2,7 m) of the open-plan offices was modeled in the ESP-r simulation environment. The simulation was carried out in two steps. The first aimed to find out if night ventilation without mechanical cooling would be able to guarantee acceptable thermal comfort. If it wouldn't, then the next step was to assess the necessary cooling capacity taking into account the building thermal mass as well as night ventilation effects.

The predictions show that the internal air temperature would be very often (202 hours) above the thermal comfort limits if there would be no mechanical cooling. The mechanical cooling should be at least 0,9kW (23W/m²) to guarantee acceptable thermal comfort in the office according to the early design simulation results. The early design simulations suggested that the high thermal mass and the night ventilation would decrease cooling energy consumption. However, there is additional cooling needed in order to obtain thermal comfort. Therefore a so-called "top cooling" system was subsequently applied.

9.3 BUILDING MONITORING

In the first year of operation there were many complaints from the open-plan office users; mainly about too high indoor temperature during the hot period of May 2002. Therefore measurements were carried out and the system performance was analysed. Finally it was found that the reason was not poor HVAC design, but poor realization. The system was not tested in cooling mode during commissioning and some components did not work properly. The heating coil valve was leaking and

11

In the early design phases for a new commercial building in Prague computer simulations were carried out in view of possible effects of night cooling ventilation. Predictions of the indoor environment and energy consumption for various options regarding cooling capacity and different outdoor ventilation rates supported the HVAC system design which included daytime top cooling and night ventilation with outdoor air combined with accumulation of cold in building constructions. After completion of the building, occupants' complaints and a set of measurements indicated some problems with the HVAC, which were subsequently solved. Long-term monitoring and further computer simulations were performed in order to optimize the control strategy of the top cooling system.

9.1 BUILDING CONCEPT

The new headquarters for the ČEZ power company (one of the top ten largest European energy utilities and the strongest business entity on the Czech electricity market) in Prague is the first headquarters building in the Czech Republic to employ night-cooling and top cooling for most of its office spaces. Occupied by ČEZ since April 2002, it won the "Czech building of the year 2002" award by the Czech ABF foundation (Dvorak 2002).

The building is divided into three parts. It has two wings (six floors above ground, 600m² each) with open-plan offices and an all-air system with top cooling and night ventilation. The central part houses the reception on the ground floor and individually air-conditioned offices on the higher floors. For night cooling, the thermal mass of the building is very important. The building features exposed concrete ceilings with ribs and concrete floors without any carpets. More than 50% of the façade is transparent. All south facing windows are fully shaded throughout the summer by external facade elements (Figure 14).

The all-air centralized system for the two wings is controlled according to the return air temperature. It is a top cooling system meaning that the capacity is less than it would be according to the current cooling load standard. The cooling capacity is based on simulations in the early design phase. There

10

thus effectively the heating was on all the time. The fans had been operated just at half speed because of noise complaints in some offices. The night ventilation was not used at all. When the major problems were fixed and a night cooling regime was introduced, subsequent monitoring proved that the system functioned satisfactorily.

9.4 THE SIMULATIONS MODEL CALIBRATION

The second stage of the work used a more complex simulation model (Figure 15) for system optimization. For calibrating this model, there were three types of measured data available. Firstly data from the building energy management system. Secondly data acquired from long-term monitoring of inside temperature and humidity and from short-term detailed measurements of indoor temperatures and velocity distribution near the diffusers. Finally weather data from the CTU meteorological laboratory.

The fifth floor of wing C (37.9x15,7x2,7m) was modeled in ESP-r as one zone including all constructional details, shading properties and internal gains. The exposed ceiling and the uncovered floor are of concrete. The façade is insulated according to the Czech standard ($u = 0,36 \text{ W/m}^2\text{K}$) and the double glass windows ($u = 1,3 \text{ W/m}^2\text{K}$; $g = 0,5$).

The result of the building model calibration based on the measured data is the working day internal gains profile as presented in Figure 16. The real equipment gain is 34% of the nominal value.

Next, the building model was extended with an explicit plant system model. This model comprises ducts, heat recovery, fan and cooling coil. The plant model was calibrated as well. The calibration results (Figure 17) show similar inside temperature and cooling flux to the zone. When comparing simulation results with measurements in a real building we should not expect a perfect fit. There are too many uncertain parameters (e.g. material properties) and unknown variables because they are not monitored (e.g. openable windows). Also the real system sensors are not very accurate. Finally, an office is not really a well mixed zone; at any point in time there may be air temperature differences within the office up to 1,5 K.

12

The calibrated building and plant models were simulated using Prague reference year weather data to find out the operation schedule with lowest overall energy consumption. It is important to include the electricity consumption for fans and chiller (cooling water source). The overall COP of the chiller system was assumed to be 2.5. Fan electricity consumption grows exponentially with flow rate, therefore just comparing cooling energy consumption does not represent the systems properly. The energy consumption of the fan was calculated as a function of flow rate.

In total, ten operation scenarios were simulated. In the first six simulations various combinations of flow rates and time periods were tested. For the next five cases the cooling coil capacity was reduced. Case 10 actually represents operation of the building without any cooling. For comparison, case FC represents the performance of the same building without thermally active ceiling (added insulation on inside surface) and floor (carpet) when just a minimum of fresh air is supplied during working hours and cooling is provided by a fan-coil system.

9.6 RESULTS ANALYSIS

Changing the flow rates during the day and night does not influence the overall energy consumption strongly as can be seen from the Cases 0 to 5 results in Figure 18. Although the coil cooling energy consumption decreases considerable with higher flow rates, the higher energy consumption of the fan results in small differences in total energy consumption. In the cases with limited cooling coil capacity (Cases 6 to 10), the overall energy consumption decreases. In the cases when the cooling capacity was limited to 5 kW or to zero (Cases 8 and 10) the inside air temperatures are above the thermal comfort limits for a significant part of the summer, which is not acceptable (Figure 19).

Finally Case 9, in which a reduced flow rate of 1,06 kg/s is applied over 24 hours during week days and the cooling coil capacity is limited to 7 kW, can be recommended. For the given weather data, the total energy consumption is estimated at 11,6 MWh representing a 12% reduction compared to Case 1. The inside air temperatures would not exceed 28°C at any time.

10 EVAPORATIVE COOLING

Applicability of direct evaporative cooling in office or residential buildings is limited due to thermal comfort considerations. If the maximum internal air temperature is 26 °C and humidity is 60%, the enthalpy of the external air should not exceed 52 kJ/kg. Analyzing the climate data it was found that there are 180 working hours when the outside enthalpy exceeds 52 and 82 hours when 26°C is exceeded as well. This is a considerable part of the cooling season. That is why direct evaporative cooling is usually combined with another cooling technology, in order to provide comfort throughout the whole year. The maximum capacity of the chiller would not decrease significantly, if such a hybrid system consists of a direct evaporative cooling device and standard chiller. However, the number of operation hours and energy consumption decreases markedly (Lain 2003).

For spaces with higher required humidity (some industrial and agricultural applications) evaporative cooling is more suitable.

For indirect evaporative cooling the situation is similar, for the few hours in the year, the outside air enthalpy is so high that the system would not work.

Although the Czech climate is semi-humid, dehumidification is not needed for non-industrial buildings. Most air-conditioning systems incorporate some dehumidification by means of cooling coil condensation. If there is no condensation (or dehumidification) anywhere in the system the inside humidity exceeds the recommended maximum as can be seen in Figure 20 (Lain 2003).

11 THE PRAGUE ZOO "INDONESIAN JUNGLE" PAVILION

The "Indonesian Jungle" pavilion is a new feature of the Prague Zoo. The indoor environment, plants and animals represent the climate and a small section of the flora and fauna typical for the tropical Indonesian jungle.

Building performance simulations were carried out during the concept design stage of the building; i.e. before the detailed design of the building and the associated heating, ventilation and air-

From the results for Case FC (fan-coil and building without active thermal mass) it is clear that the cooling energy consumption would be much higher for the fan-coil system, but the overall electricity consumption would be the lowest of all cases. The chiller capacity for the fan-coil system is 27 kW, it is almost 3 time more than the optimized top cooling system. The investments and maintenance costs for the chiller will be therefore much higher.

9.7 CONCLUSION

To design low energy cooling using night ventilation, computer simulation is a very important tool for predicting comfort without mechanical cooling and/ or the required cooling capacity for hybrid systems.

Internal gains from office equipment are very important in the thermal balance of office buildings. In reality the thermal gain from office computers and such is much lower than the nominal power input on the name-plate.

Design and commissioning of low energy systems is usually more complex than for standard HVAC systems. It requires better cooperation of all participants in the building design, construction and maintenance. Unfavourable experiences with some realized systems are mostly due to the lack of information exchange. Sometimes during construction a system is simplified in such a way that it is not able anymore to work properly. Also, the systems are often operated without any knowledge about its principles.

In top-cooling and all-night ventilation systems the electrical energy consumption of the fans is very important. Due to the relatively high COP of mechanical cooling systems, even large cooling energy savings by night ventilation can be counter balanced by the electrical energy consumption of the fans. The system should be designed with low pressure losses in order to reduce the fan energy consumption.

conditioning (HVAC) systems. The aim of the simulation study was to support the HVAC system designers. The main objectives were to assist in deciding the system concept by estimating energy demands and predicting maximum loads for sizing the HVAC system and main components.

11.1 BUILDING DESCRIPTION AND MODEL

The pavilion is basically a transparent (acrylic) dome with a surface area of 1900 m² covering a volume of 14700 m³. Both human visitors and jungle animals (monkeys, birds and others) are present in the building. The majority of the animals are in the main space; i.e. they have no special housing in which a specific indoor environment could be kept. The animals are separated from and protected against people (and vice versa) by water basins. The indoor environment represents the Indonesian jungle outdoor climate. Zoological experts specified the design brief. The daytime indoor temperature should - all year round - be maintained between 22 and 25 °C. Short excursions outside this range are allowed down to 18 and up to 35 °C. The relative humidity (RH) should be kept over 70%. At nighttime lower temperatures (by 4 to 6 °C), with a minimum of 18°C, are allowed. The temperature of the water in the basins is not controlled. The base of the building is constructed of concrete and has thermal insulation. The base is partly inserted into the ground massive, which helps to keep a stable indoor climate. A transparent elliptical dome forms the sidewalls and roof. The dome has an acrylic (Plexiglas) double-skin construction.

The size and shape of the ESP-r computer model is based on similarity with the real building in terms of volume and external surface areas.

The elliptical plan was changed into a polygonal shape. The arced roof (a part of ellipsoid) was approached as a shape with 13 flat surfaces as shown in Figure 21. The space was divided into 3 thermal zones according to the volumes and associated future usage of the building. The two large zones A and B represent in reality one open space with – perhaps – different temperatures. Therefore these two zones are divided by a horizontal fictitious surface. The smaller zone C represents a special cave-like corridor exposition area for nocturnal animals.

Casual sensible and latent (moisture) heat gains were considered both for people and for the animals. Infiltration and ventilation was modelled by assuming specific air change rates as detailed below.

11.2 MODEL "CALIBRATION"

Model calibration is a very important quality insurance step in the modelling and simulation process. However, it is very difficult since there are no experimental results available. Also, for the current building it is not even possible to compare the results with typical values for similar buildings because such values do not exist to the best of our knowledge.

One of the few practical 'options' is to very carefully analyse the simulation results so as to gain increased confidence in the model based on professional knowledge and intuition.

Another practical option is investigate the sensitivity of the results to uncertain input parameters. In the current case, the casual sensible and latent heat gains due to people and animals are very uncertain input parameters. To investigate the sensitivity of the results to number of people and animals, the model was run for 0, 100 and 200 persons. One person's production was set to 77 W sensible heat and 83 W latent heat.

As can be seen in Figure 22 the simulation runs prove that the system loads and/or indoor environment are almost independent of the number of visitors and also that the influence of the animals is negligible.

After calibration, the model was used for simulations in order to find the 'optimum' fresh air ventilation rate. The simulations were run for a winter period assuming three levels of fresh air ventilation: 0, 0.5 and 1 ACH. After evaluating the resulting heating losses, it was concluded that the fresh air supply should be as low as possible. For the reasons of indoor air quality (although this cannot be specified for monkeys) it was recommended that the fresh air supply should not be less than 0.5 ACH. For the summer, simulations were run assuming fresh air ventilation rates of 0, 0.5, 1, 2, 3, 4 ACH. The results show that increasing the fresh air ventilation rate decreases the cooling

11.4 HVAC SYSTEM CONCEPT

Based on extensive modelling and simulation work, the following HVAC system concept was recommended. Natural ventilation cannot be used; the building is relatively flat (low height) and it is not possible to create substantial ventilation openings in the lower part. Apart from the entrance most of the building is underground. Due to the shape and materialization, it is difficult to create openable parts in the roof. The incoming air has to be conditioned (especially in winter).

Two air-conditioning units (24000 m³/h each) will supply air to the pavilion; two units were recommended because of transport to the site, installation, space requirements, regulations and for safety in the case of system failure. The pavilion will be heated mostly by hot air. To use heat recovery preheating above 0 °C will sometimes be necessary in order to avoid freezing of the heat exchanger. The heat recovery efficiency can be expected to be relatively high because of the high enthalpy (very humid) of the outgoing air. The amount of fresh air supply should be minimal in order to save energy. During the summer more outside air will be used. The supply air should be humidified in the air-handling unit and by spraying water inside the pavilion. Mechanical cooling is needed only during a fraction of the time.

Cold storage has not yet been considered in this stage of the design process.

12 GROUND COOLING

The Czech Republic has quite a rugged topography on a relatively small area. There are regions with very high underground water levels and artificial lakes (south Bohemia) as well as dry plains, mountains and river valleys. The soil differs very much from place to place and it is necessary to do geological prospecting to find local ground properties for underground systems.

Small air ground cooling systems are currently popular for low energy family houses with central air system in order to decrease summer peak temperatures. There is only one larger building in the

energy demand, but increases the peak cooling load. An average fresh air ventilation rate of 3 ACH was recommended as the best compromise.

Direct evaporative cooling by spraying water in the pavilion interior was considered in order to adiabatically cool the air and thus to reduce the summertime cooling energy consumption and to lower the maximum cooling loads. This was considered an interesting option since the Czech Republic has a relatively dry summer climate while the jungle pavilion requires high levels of relative humidity; i.e. in the range of 70% to 90%.

As can be seen in Figure 23, the simulation results indicate about 50 kW or 25% reduction in maximum cooling load due to evaporative cooling. The time when the cooling system would be in use will be reduced from 2000 hrs to about 1000 hrs per year. The number of operating hours with high cooling loads, e.g. loads over 120 kW, will occur during 80 hours per year only.

In terms of cooling energy demand the differences are even bigger. Without direct evaporative cooling the cooling energy demand over a typical summer amounts to 89 MWh. With direct evaporative cooling and a maximum indoor relative humidity of 70% this reduces to 41 MWh (54% reduction). With a maximum relative humidity of 90% the cooling energy demand reduces to 13 MWh (85% reduction).

11.3 HVAC SYSTEM FAILURE RESPONSE

The study included predictions on what will happen in case the air-conditioning system would fail and recommendations on how to deal with such emergencies in winter and summer.

For both situations, short periods with extreme temperatures were selected.

Figure 24 shows the summer situation. Critical will be the rapid rise in temperature and rapid drop in relative humidity. In the case of emergency this may be partly compensated by spraying water and by introducing outdoor air by opening "windows" and also shows the winter situation. Critical will be the rapid drop in indoor temperature. In case of emergency it is recommended to tightly close the building and move the animals to some heated boxes.

Czech Republic which used ground cooling by means of buried pipes. This is the Slunakov Ecological Education Center (SEV) designed for the city of Olomouc (Figure 25).

13 CONCLUSIONS

For passive and low energy cooling technologies, the dynamic behavior and interactions of building, systems, occupants and environment is very important. To design such systems and verify its performance the standard design methods based on peak gains are not suitable. In contrast to the traditional simplified calculating methods (not considering the system dynamics), computer based modeling approaches reality much closer. The use of computer modeling and simulation for the design and evaluation of buildings and HVAC is quickly moving from the research and development stage into everyday engineering practice.

The benefits of using low energy and passive technologies are potentially very high in the Czech republic. Although there exist no major technical barriers, these technologies are not rapidly introduced due to economic reasons.

Only for a few recent offices a passive cooling concept was considered during the design. There exists no large new office building which was designed to use only passive cooling. Designing office buildings with more effective thermal mass and good quality shading in order to lower cooling loads is nowadays considered as good practice.

The design and commissioning of low energy systems is usually more complex than using standard air-conditioning. It requires better cooperation of all participants in the building design, construction and maintenance. Bad experiences with some systems are mostly due to lack of information exchange.

Finally, we would like to make the point that for design support such as in the current case it is really necessary to have sufficient domain knowledge. As Banks and Gibson (1997) rightfully point out "Simulation is a discipline, not a software package; it requires detailed formulation of the problem, careful translation or coding of the system logic into the simulation procedural language (regardless

of the interface type), and thorough testing of the resulting model and results. There are at least two different skills required to be successful at simulation. The first skill required is the ability to understand a complex system and its interrelationships. The second skill required is the ability to translate this understanding into an appropriate logical representation recognized by the simulation software." So it is not a case of making software so easy to use that (almost) anyone can use it, but rather to focus on how to make building performance simulation software more efficient and easier to use for domain experts. We feel that this is a rather different approach than the one which is often advocated and pursued in 'simulation for design' papers and research.

REFERENCES

Banks, J and R R Gibson 1997. "Simulation modelling – some programming required", IIE Solutions, February 1997.

Barnard N. and Jaunzens D. 2001. Low Energy Cooling – Technology Selection and Early Design Guidance, Building Research Establishment Ltd, London.

Barták, M., Drkal, F., Hensen, J., Lain, M. et al., 2001, Simulation for (Sustainable) Building Design: Czech Experiences, Clima 2000 – Napoli, Milan, p. 354-363.

Bartak, M., Drkal, F., Hensen, J., Lain, M., 2001, Design Support Simulations For The Prague Zoo "Indonesian Jungle" Pavilion, BS 2001, IBPSA, p.841-845.

Beausoleil-Morrison I. 2000, The Adaptive Coupling of Heat and Air Flow Modelling within Dynamic Whole-Building Simulation, PHD thesis, University of Strathclyde, Glasgow UK.

Behne M. 1997. Alternatives to Compressive Cooling in Non-Residential Buildings to Reduce Primary Energy Consumption, Final report, Lawrence Berkeley National Laboratory, Berkeley, California.

Bunn, R 2001. "Specifying on the net", Building Services Journal, nr.2, pp.49-50., Chartered Institute of Building Services Engineers (CIBSE), London.

- Figure 1: The building as an integration of energy systems.
- Figure 2: Cumulative distributions of the dry-bulb temperature (left) and humidity ratio (right) comparing Prague to five other climates (Bene 1997).
- Figure 3: Outside view of the building and the ESP-r model of the considered part
- Figure 4: Temperatures of indoor and outdoor air (ventilation without air-conditioning)
- Figure 5: Optimized operation of air-conditioning system (indoor air temperature set point is 26 °C)
- Figure 6: ESP-r model of the building
- Figure 7: Diagram of thermal zones and airflow network
- Figure 8: Internal surface temperature on the north wall and dew point temperature during the winter period
- Figure 9: Air temperatures during a typical winter week
- Figure 10: Air temperature distribution in the transversal section for cases with open and closed roof windows left and air velocity distribution in the central longitudinal right
- Figure 11: Operative temperature during two summer weeks assuming infiltration only, different glazing types, without (left) and with ceiling cooling.
- Figure 12: Operative temperature during two summer weeks assuming night ventilation (left) and day time ventilation (right), different glazing types, without ceiling cooling.
- Figure 13: Air temperature difference variation in Prague during the cooling season.
- Figure 14: Principle of the shading and of the nighttime forced ventilation
- Figure 15: The ESP-r model of the building 5th floor
- Figure 16: The internal gains profile for 1 day
- Figure 17: The building with plant system calibration results
- Figure 18: Comparing el. Energy consumption over whole summer for all simulated test cases.
- Figure 19: The inside air temperature distribution
- Figure 20: Cumulative distribution of indoor relative humidity for all air system (right) and indirect evaporative cooling (left)

Duška M., Drkal F. and Lain M., 2004. Tepelné zisky z vnitřních vybavení administrativních budov, Vytápění, Větrání, Instalace magazin, p. 198-201.

Dvorak J. 2002. Hlavní sprava CEZ: nocni chlazení, in Proc. Simulace budov a techniky prostredi 2002, IBPSA-CZ, p. 15 - 17.

Heap R.D. 2001. Refrigeration and air conditioning – the response to climate change, Bulletin of the IIR-2001-5.

Hofmeister, O., Kopecký, P., Tywoniak, J., 2004, SLUNAKOV Ecological Education Center – Basic information, internal report, Prague.

IEA, 1995, Review of Low Energy Cooling Technologies, Natural resources Canada, Ottawa, Canada, 88 p.

Lain, M., Drkal, F., Hensen, J., Zmrhal, V., 2004, Low Energy Cooling Techniques for Retrofitted Office Buildings in Central Europe, Ventilation and Retrofitting Prague, AIVC Brussels, p. 79-84.

Lain, M., Duška, M., Matějček, K., 2003, Applicability of Evaporative Cooling Techniques in the Czech Republic, Proceedings 21st International Congress of Refrigeration, Washington DC, IIR Paris.

Liddament, M.W., 2000, Low energy cooling, ESSU, Coventry, U.K., 32 p.

Santamouris, M., Asimakopoulos, D., 1996, Passive Cooling of Buildings, James&James Ltd., London, U.K., 472 p.

ESP-r (Environmental Systems Performance – research) software www.esru.strath.ac.uk

This research was supported by research plan MSM6840770011.

- Figure 21: Wire frame CAD drawing of the pavilion (left) and ESP-r model of the pavilion (right)
- Figure 22: Sensitivity to sensible heat gains from people (or animals) of the cooling load during a warm summer day (left) and during a cold winter week (right)
- Figure 23: Reduction of the cooling load due to direct evaporative (adiabatic) cooling
- Figure 24: Indoor conditions immediately before and after HVAC system failure on a warm summer afternoon (left) on a cold winter afternoon (right)
- Figure 25: Ground plan of the Slunakov building

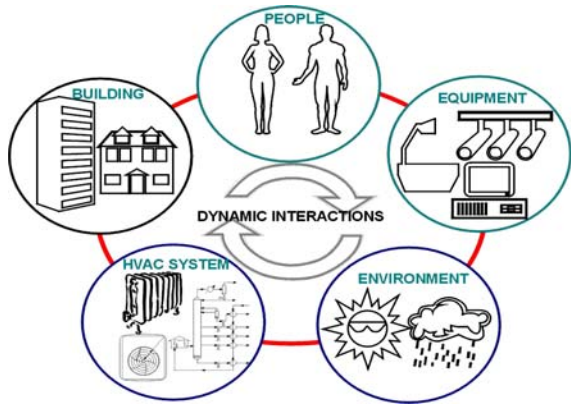


Figure 1

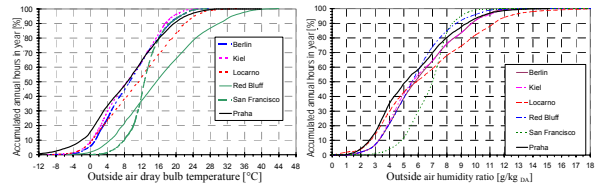


Figure 2

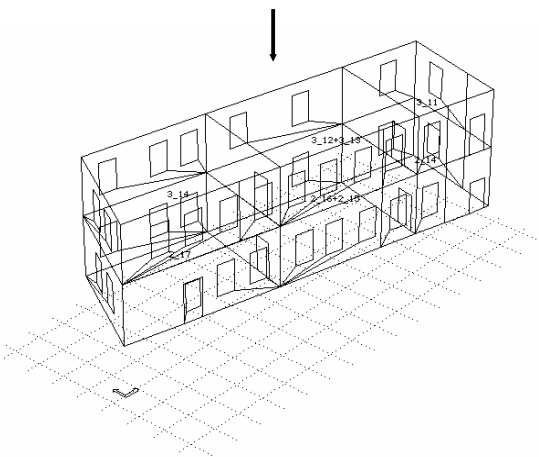


Figure 3

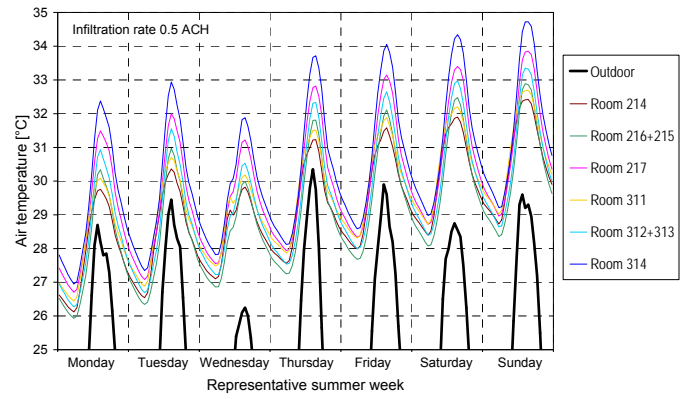


Figure 4

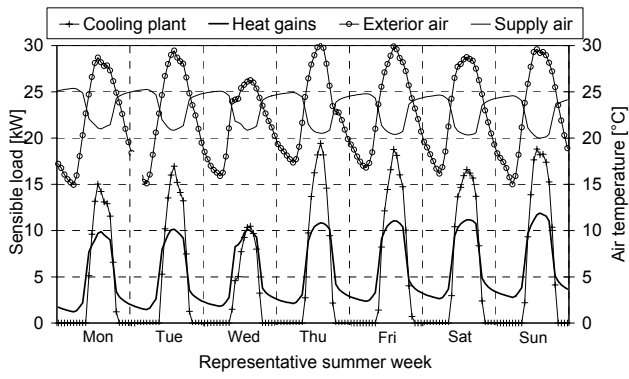


Figure 5

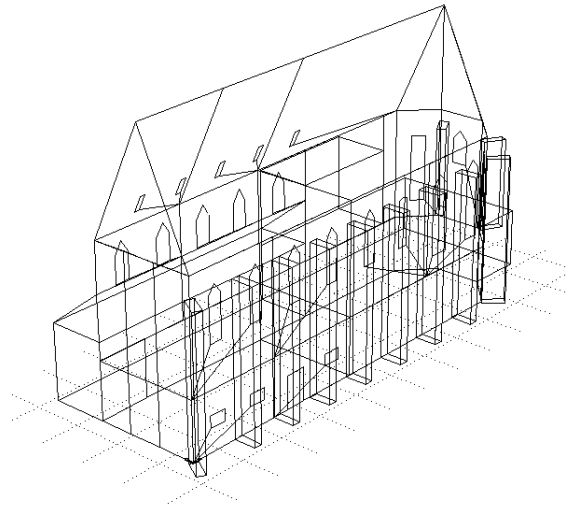


Figure 6

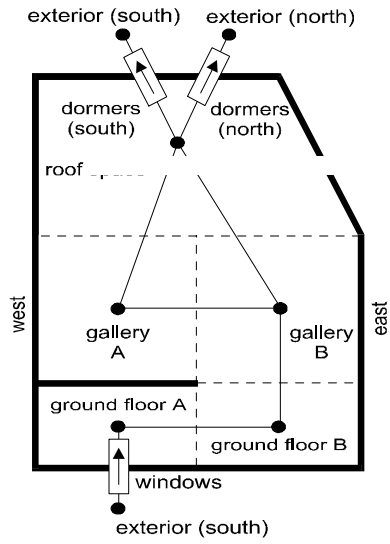


Figure 7

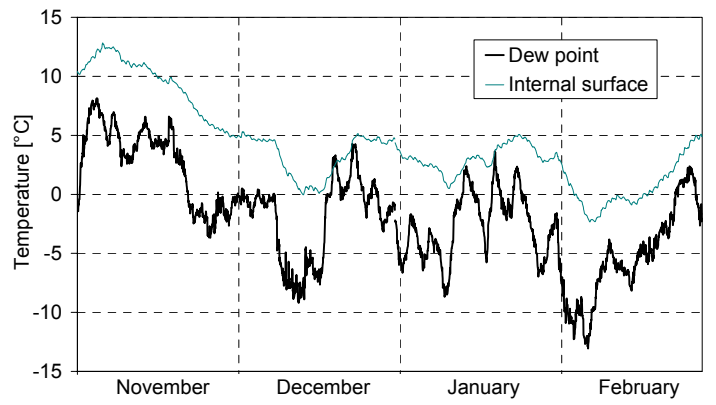


Figure 8

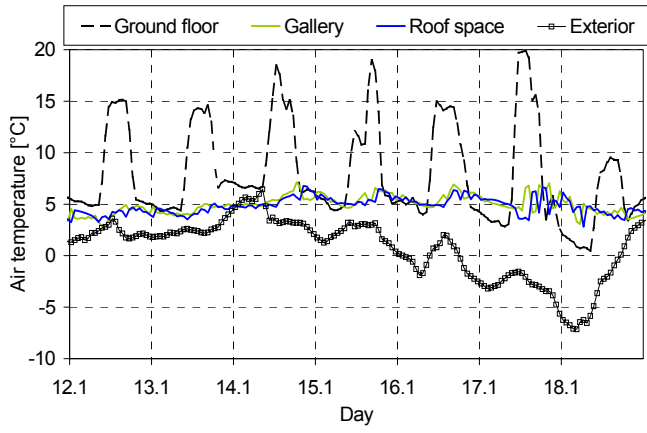


Figure 9

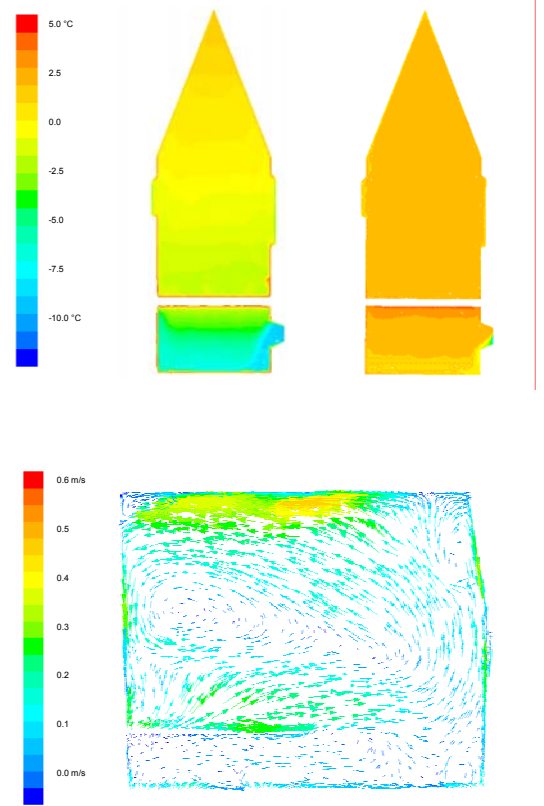


Figure 10

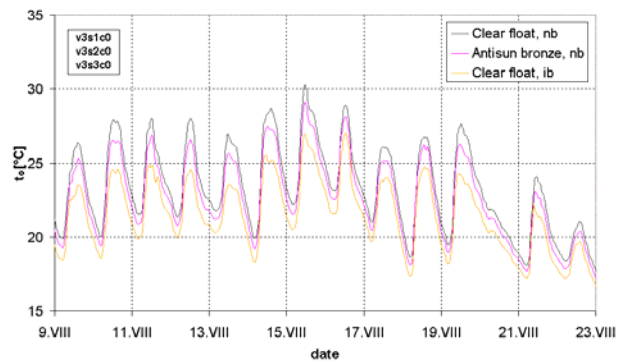
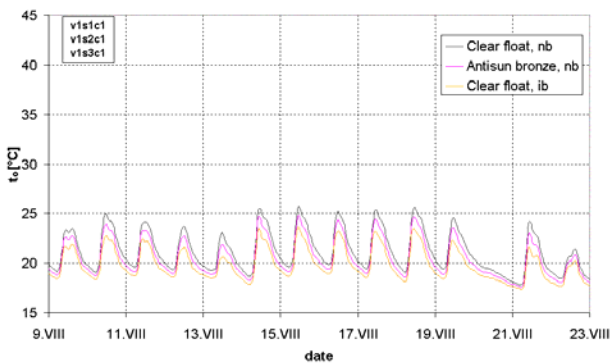
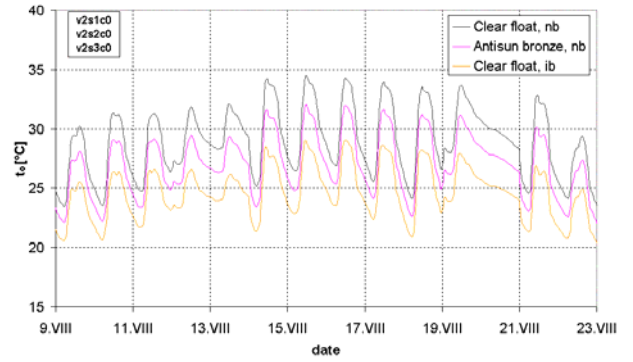
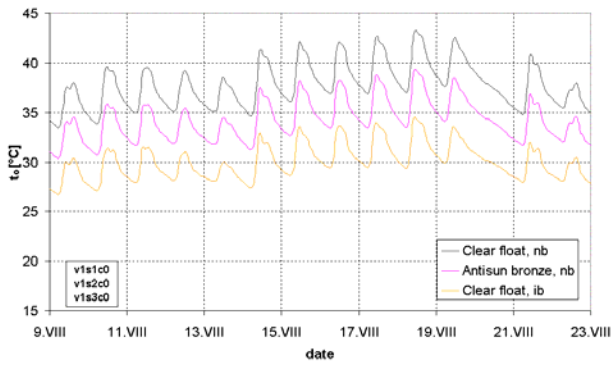


Figure 11

Figure 12

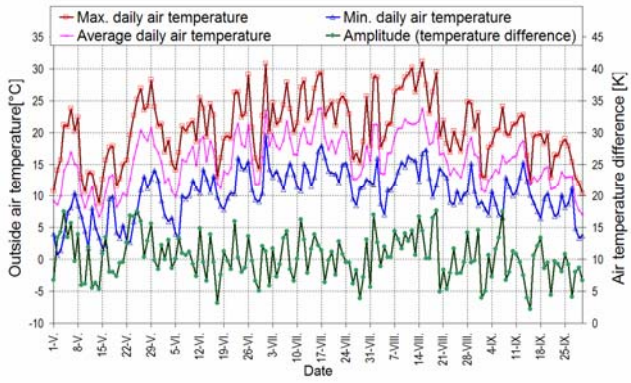


Figure 13

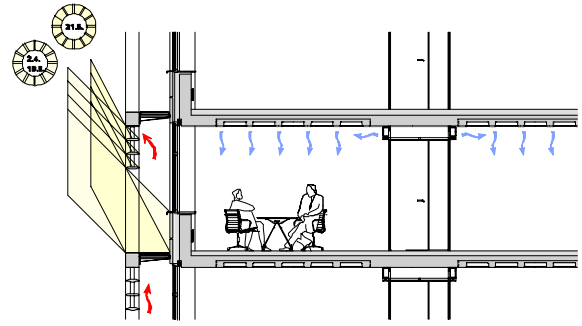


Figure 14

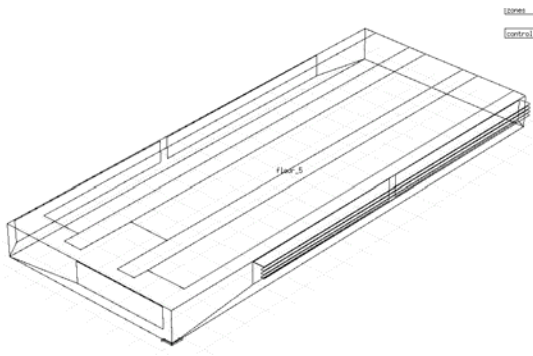


Figure 15

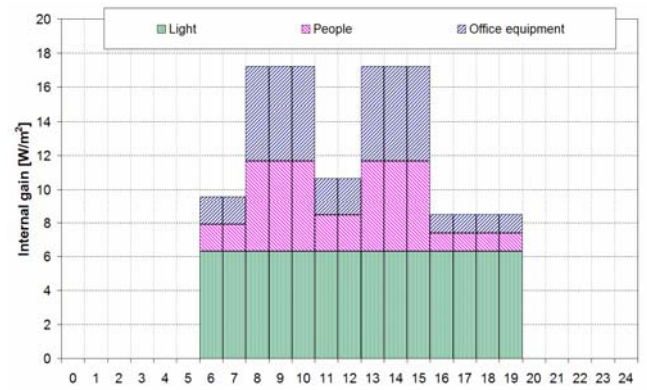


Figure 16

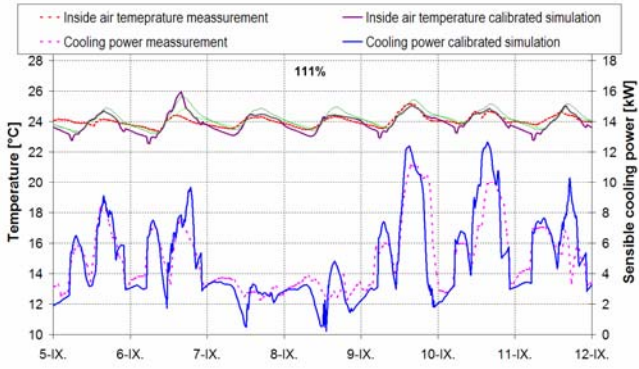


Figure 17

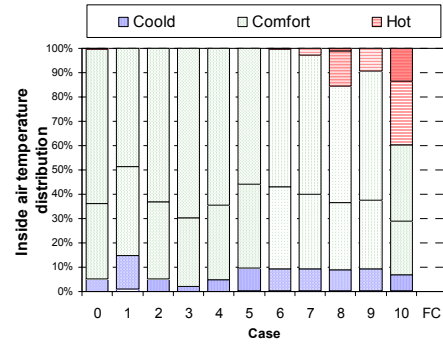


Figure 18

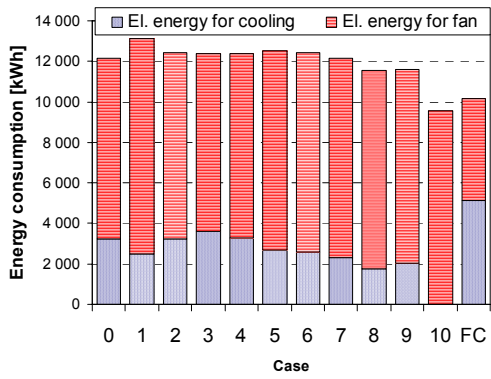


Figure 19

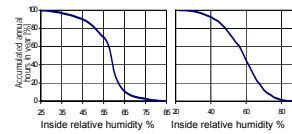


Figure 20

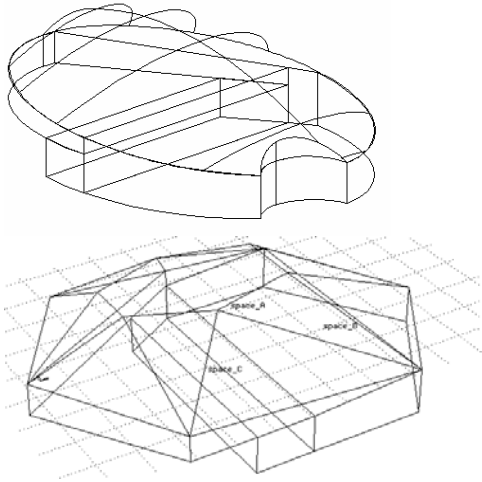


Figure 21

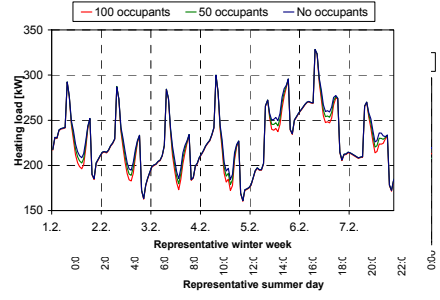


Figure 22

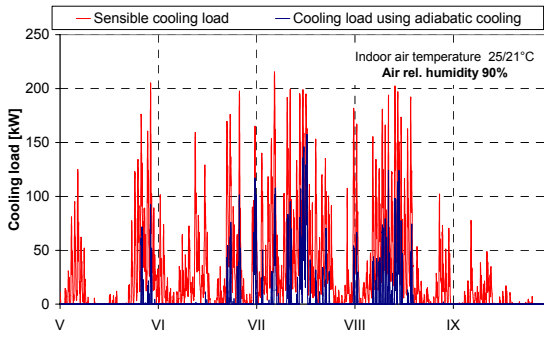


Figure 23

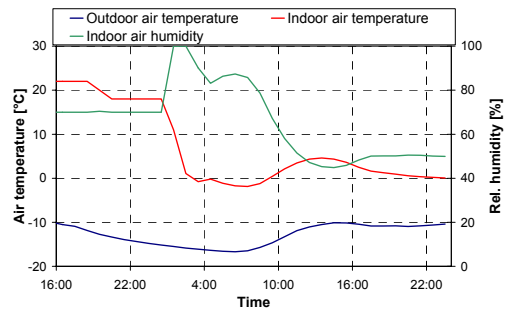
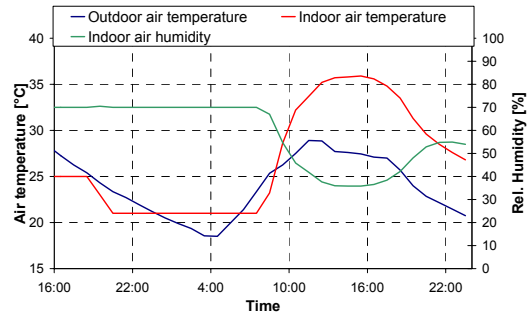


Figure 24

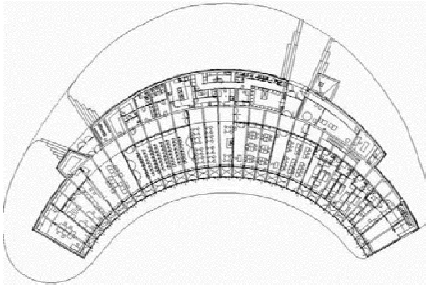


Figure 25

Table 1: Cooling degree hours and enthalpy hours

Town	CDH ₂₅	EH _{25/40} (kJ/kgDA)	CDH ₁₈	EH _{18/40} (kJ/kgDA)
Prague	361	3 047	4 581	25 198
Dresden	527	3 040	5 154	28 068
Stockholm	150	1 350	1 000	16 425
Zurich	426	1 658	4 757	16 380
New York	2 570	25 698	15 942	68 783
Toronto	837	12 294	7 643	40 831

Figure 26

Table 2: Number of working hours during three summer months with the operative temp. in a specific interval

Operative temperature	from	18	24	28	32
	to	18	24	28	32
Ventilation	Glazing	Without ceiling cooling			
Infiltration	Std.	0	0	0	143 583
Infiltration	Antisun	0	0	74	346 306
Infiltration	Blinds	0	48	370	271 37
Night vent.	Std.	0	104	367	218 37
Night vent.	Antisun	0	270	337	119 0
Night vent.	Blinds	5	487	218	16 0
Day vent.	Std.	133	415	172	6 0
Day vent.	Antisun	165	434	126	1 0
Day vent.	Blinds	227	464	35	0 0

Figure 27