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DESIGN SUPPORT SIMULATIONS FOR THE PRAGUE ZOO "INDONESIAN JUNGLE" PAVILION

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ABSTRACT

This paper describes the modelling and simulation work that was carried out to support the design team of the new "Indonesian Jungle" pavilion in Prague Zoo. This pavilion is basically a very large transparent (acrylic) dome maintaining a warm and humid jungle-like indoor environment. Problematic issues include very high solar gains in summer, very high heat losses in winter, and potential condensation against the roof at various times throughout the year.

After elaborating the above, the various modelling problems associated with this building are discussed. These include problematic parameter estimation for moisture production and infiltration, and the issue of how to calibrate the generated model. The simulations and results are outlined, and the transformation of these into design information is discussed.

The paper finishes by indicating directions for future work in order to be better equipped for addressing design problems such as the one described in this paper.

INTRODUCTION

The “Indonesian Jungle” pavilion will be a new feature of the Prague Zoo. The indoor environment, plants and animals will 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-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.

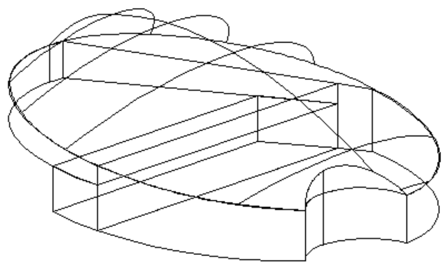

Figure 1 Wire frame CAD drawing of the pavilion

BUILDING DESCRIPTION

The pavilion is basically a transparent (acrylic) dome with a surface area of 1900 m^2 covering a volume of 14700 m^3. 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.

MODEL

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.

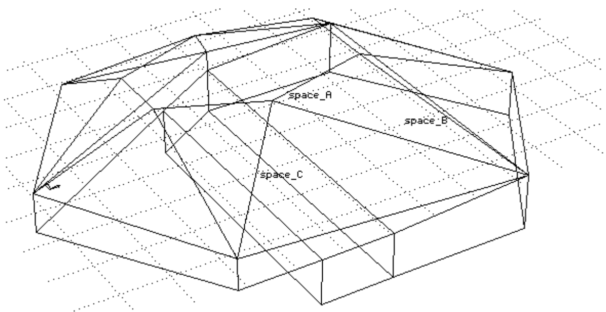

Figure 2 ESP-r model of the pavilion

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 1. 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.

The optical properties of the double-skin acrylic material of the roof were available only for normal (perpendicular) direct solar radiation. The angular optical properties were estimated using the WIS software.

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.

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 2a and Figure 2b 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.

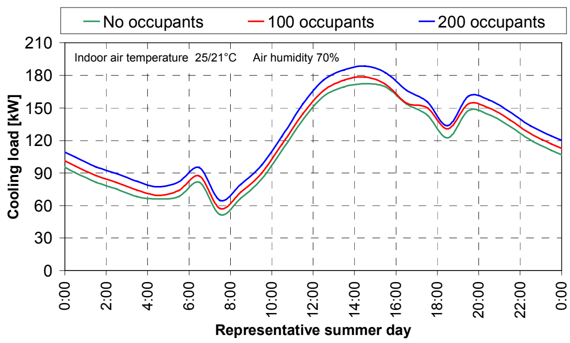

Figure 2a Sensitivity to sensible heat gains from people (or animals) of the cooling load during a warm summer day

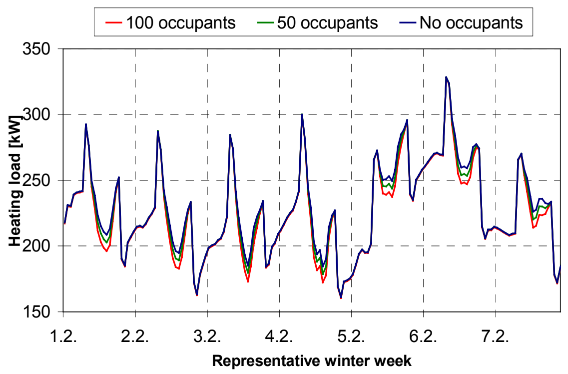

Figure 2b Sensitivity to sensible heat gains from people (or animals) of the heating load during a cold winter week

VENTILATION RATE

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 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

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%.

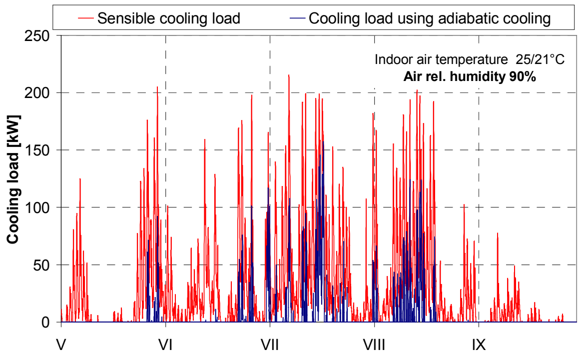

Figure 3 Reduction of the cooling load due to direct evaporative (adiabatic) cooling

As can be seen in Figure 3, 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).

VAPOUR CONDENSATION

With the high indoor relative humidity, which is required, it is more than likely that during the winter considerable condensation will occur on the inner surface of the roof. Simulations were carried out to predict the inner surface temperatures. These could then be compared with the predicted dew point temperature of the indoor air. Based on similarity between heat and mass transfer condensation rates up to 30 kg/hr would have to be expected; this is assuming inside air temperature of 22°C, surface temperature of 5°C, convective heat loss through the roof of 30 kW, and absolute moisture content difference between air and surface of 5 g/kg. In the first approximation, the condensation rate of 30 kg/hr has to be compensated by the additional (latent) space heat load of 20 kW. In reality this will be less because the surface temperature will rise due to the condensation heat, and subsequently the condensation rate will decrease.

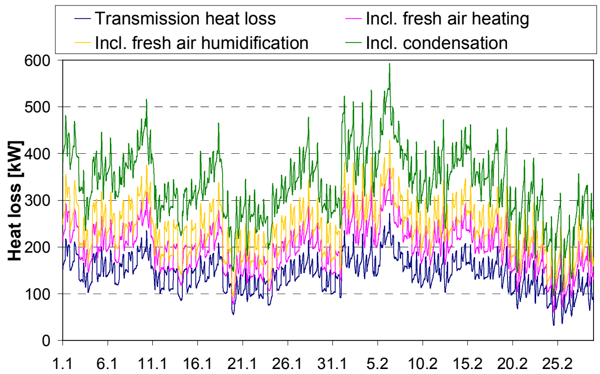

Figure 4 Breakdown of winter heat losses in transmission, ventilation and condensation heat losses.

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.

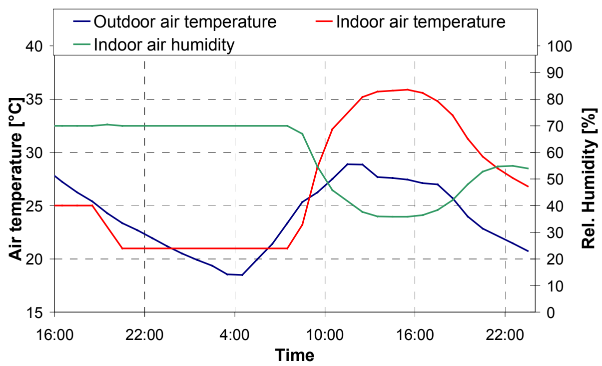

Figure 5a Indoor conditions immediately before and after HVAC system failure on a warm summer afternoon

Figure 5a 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".
Figure 5b 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.

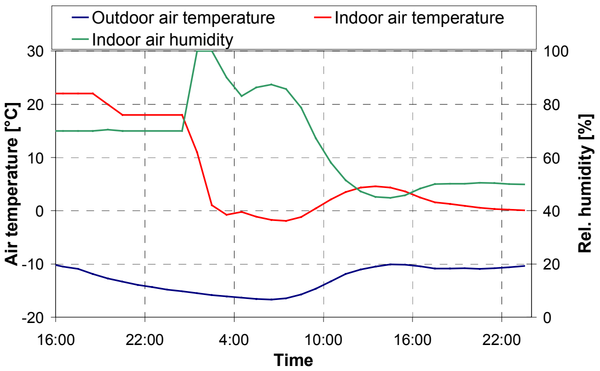

Figure 5b Indoor conditions immediately before and after HVAC system failure on a cold winter afternoon

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 m^3/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.

Table 1 Overview of HVAC system characteristics and design parameters

Summer		**Winter**	
Outdoor design conditions			
Air temperature	30 °C	Air temperature	-20 °C
Humidity	50 %	Humidity	95 %
Enthalphy	65 kJ/kg K		
Global solar radiation	800 W/m^2		
Inside design conditions			
Maximum night time air temperature	21 °C	Maximum night time air temperature	18 °C
Maximum day time air temperature	25 °C	Maximum day time air temperature	22 °C
Minimum relative humidity	70 %	Minimum relative humidity	70 %
Air flow rate			
Fresh air supply	48150 m^3/h	Fresh air supply	8025 m^3/h
Total air supply	48150 m^3/h	Total air supply	48150 m^3/h
Supply air temperature difference			
Cooling mode	-4 K	Heating mode	12 K
Thermal loads			
Maximum cooling	100 kW	Maximum pre-heating	62 kW
		Maximum covered by heat recovery (η = 0.7)	36 kW
		Maximum first stage heating (before humidifier)	230 kW
		Maximum second stage heating	200 kW
Water consumption for humidification			
In the air-handling unit	125 kg/h	In the air-handling unit	304 kg/h
In the pavilion itself	100 kg/h	In the pavilion itself	100 kg/h

FUTURE WORK

For the current building itself, future work could usefully involve the following.

Due to scarce resources, the current study had to be limited to the activities briefly described in the current paper. We hope to find additional resources in order to use the model to optimise design and operation of the HVAC systems in terms of indoor climate requirements and energy consumption.

After completion of the building, we hope to be able to monitor the HVAC system and the indoor conditions, in order to compare the predictions with reality.

In more general terms, but still related to the kind of design support as described in the current paper, we would welcome – amongst others - future work as follows.

It would be very useful to have databases with parameters for operational characteristics (e.g. sensible and latent casual heat gains, infiltration and ventilation estimates, etc.). This type of data exists but very fragmentary. Perhaps this could be an activity supported/ steered by IBPSA?

Ideally building material and component manufacturers would make technical documentation (including the parameters needed for building performance modelling) on-line available. This is starting to happen but there are still "one or two mountains to climb" (Bunn 2001).

Very often there is a mismatch between the data provided by the manufacturers and the parameters needed for building performance modelling; e.g. in case of the optical properties of the acrylic double-skin transparent roof material. Somehow the manufacturers should be convinced that it would be useful to provide the missing data. Could there be a role in this for IBPSA?

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.

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

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

WIS (Windows Information System) software erg.ucd.ie/wis