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Innovative Design Concept for the New Bangkok International Airport, NBIA

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ABSTRACT

Thermal and visual comfort for the occupants of a room are not defined by air temperature only, but also radiation with its three components solar radiation, daylight and heat radiation has to be taken into account (among other factors such as humidity, air speed and occupant activity and clothing levels). In hot climates the optimization of room comfort is a challenging task due to the high solar radiation over the whole year.

In intelligent buildings new material developments are applied optimizing the building envelope in an integral building design process. New solutions for weather, noise and heat protection are developed, where building envelope and installed mechanical equipment work together creating optimal comfort at minimum energy consumption.

This approach was used in the design of the New Bangkok International Airport, NBIA to develop an optimized building concept in a design team comprising the architects, structural and mechanical engineers, HVAC, acoustic and climate engineers.

Figure 1 Model of the terminal and concourse buildings

BOUNDARY CONDITIONS

In Bangkok, the climate is characterized by temperatures of 25 to 35 °C and a high level of relative humidity all the year round. The annual horizontal solar radiation total is more than 1,500 kWh/m²a and results in a solar radiation of 1,000 W/m² on many days of the year with solar altitudes near the zenith.

The situation of an international airport with 24-hours working days and high internal heat loads from people, electric equipment and lighting combined with the desired indoor climate conditions of 24 °C room temperature and 50 to 60 % relative humidity call for permanent cooling and dehumidification within the building and a sophisticated concept for the envelope to minimize the effects of the external solar loads.

CONCEPT DEVELOPMENT

This approach was used in the design of the New Bangkok International Airport, to develop an optimized building concept in a design team comprising the architects, structural and mechanical engineers, HVAC, acoustic and climate engineers.

For the terminal building of the NBIA with a length of 440 m and a width of 110 m the technique of shading by large overhangs was applied, but at the same time a roof created that allows daylight to pass through. Large external trellis blades that face to the south and open up to the north provide effective shading for direct sunlight allowing diffuse indirect light from the sky to enter the building. Proper daylighting levels for the terminal hall and views through the roof to the sky in combination with sun protection are achieved. The shading trellis blades are naturally ventilated and located outside the building envelope, so their absorbed solar heat does not enter the building.

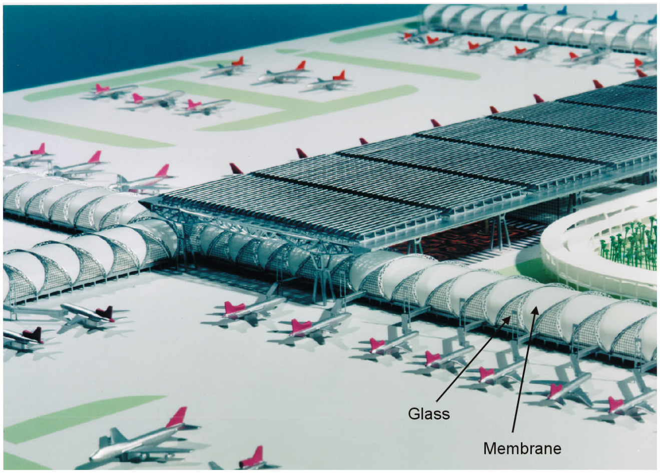

Figure 2 Model of the New International Bangkok Airport

In this case the separation of weather and sun protection layers leads to an optimized result as a starting situation for the air conditioning in the terminal hall, because most of the solar radiation is prevented from entering the terminal hall.

Air conditioning of large volume enclosures with internal building elements creates a high cooling demand in relation to the actually occupied space. In the case of the NBIA the total volume of the building is split into unconditioned zones at higher levels and cooled occupied zones at low levels drastically reducing the total cooling demand because mechanical cooling is applied only in spaces where it is actually needed.

Two different mechanical systems for cooling are used. First there is a radiant floor cooling directly removing solar and heat radiation hitting the floor. The floor surface stays cool and therefore thermal comfort is increased.

The second is an air displacement system with controllable air stream supplying cooled air to the room at floor level and at low velocity. The system uses a share of return air for the rejection of convective heat loads and provides the room with the required amount of cooled and dehumidified fresh air. Due to the fact that warm air rises, a thermal stratification in the hall is induced, with cool air at the bottom and warm air at the top, which is supported by the radiant floor cooling. The conditioned zone is limited to the air volume up to a height of 2.5 m directly above the floor in each occupied space.

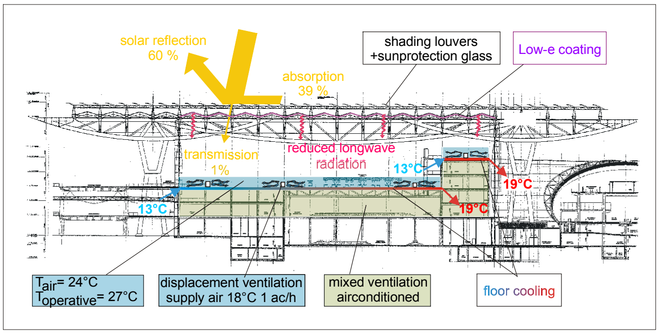

Figure 3 Climate concept for the terminal building

In the unconditioned higher levels below the roof the air warms up to about ambient temperature. The reduction of conditioned air volume is reducing the cooling loads of the building and also decreases the need for thermal insulation of a large part of the building envelope.

The passenger lounges are situated in the concourse building, which adjoins the terminal and has a total length of about 3500 m. The same concept for air conditioning is used here, but in this case the boundary conditions are different.

The envelope is constructed using two different groups of materials which are alternating along the concourses, transparent glazed facades for outside views and a translucent membrane roof for daylighting.

The glazed parts use single laminated glass units with different values for transmission, reflection and absorption of solar radiation and daylight depending on their position on the envelope. Using ceramic frit of different densities and a sun protection coating the intended material properties of the glass are achieved. In the lower parts of the envelope more glazing is applied and a lower degree of fritting is used to allow a good view to the outside. In the roof parts less glazing with a denser frit is used to achieve good solar protection against the high sun of Thailand keeping these parts of the envelope optically transparent.

The membrane parts of the envelope are constructed using a translucent multi-layer membrane assembly that allows a part of the sunlight to pass as diffuse light into the building. Due to its low specific weight and its high strength these membranes can be used in wide spanning roof constructions. The achieved savings in the amount of material used results in a cost effective building envelope construction. This translucent roof construction ensures sufficient daylighting levels for the building interior.

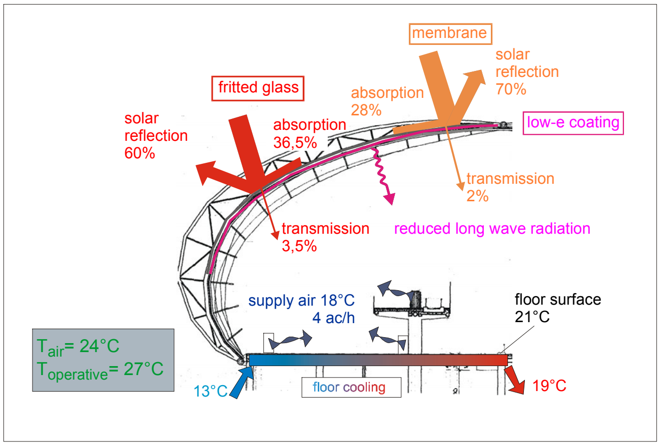

Figure 4 Climate concept for the concourse areas

In addition to this, the membrane construction works as a buffer layer for sound protection from the outside (aircraft noise) and from the inside (room acoustics). Between the weather protecting outer membrane made of teflon coated glass fibres and the inner membrane translucent sound baffles are mounted with an air gap on both sides. This baffle layer absorbs noise from the outside and the inside.

The inner membrane is a laminate of two layers. The layer facing the room is a low-e coated transparent foil being in radiative exchange with all internal surfaces of the building.

Thin metal coatings block the radiative heat exchange between the warm membrane construction and the internal building parts and is transparent for daylight and sound due to its very low thickness. This low-e coated surface has an additional advantage. Instead of radiating heat from the hot roof the radiation of the cooled floor surfaces is reflected to the room by this low-e coating which is improving thermal comfort for the occupants as they thermally sense cooler surrounding surface.

CONCEPT VERIFICATION BY SIMULATION

The energy and ventilation concept developed by the project team was checked by simulation programs in order to prove that the suggested solutions will work in reality.

A dynamic building simulation was carried out to examine the thermal loads of the building and the change in temperature and humidity, to detect possible problems with condensation and to determine the expected cooling loads and the effects of the radiant floor cooling.

Furthermore, daylight simulations help evaluate illuminance levels throughout the building resulting from daylight passing through the translucent / transparent building envelope, and can be used to detect problems with glare effects.

Stationary and transient fluid dynamic simulations (CFD) have examined the structure of the thermal stratification and the movement of humidity within the building. The CFD simulations help specify ascending and descending air streams and identify the need to separate some areas from one another with regard to air movements.

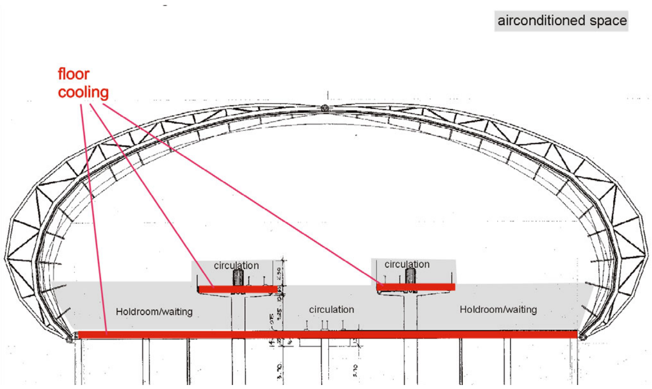

Figure 5 Cross-section view of a typical concourse building showing separated zones of the thermal building model and cooled floor areas

Thermal concept evaluation is based on selected crucial parts of the building, which have been carefully examined in a dynamic building simulation carried out with the simulation program TRNSYS (1). From the existing hourly weather data for Bangkok a period with extremely high daily top temperatures of 34 °C and a horizontal solar radiation of 1,000 W/m² was chosen as the basis for comparing several concept variants.

The model has four thermal zones: First, an air conditioned zone, situated on the bottom level, comprising passenger lounges and corridors. Second, above the former, a zone with multi-level corridors and wide-ranging people mover, which is also supplied by an air displacement system. Both zones are provided with radiant floor cooling. There are two more zones above the former, which have no air conditioning, no supply air inlets and no discharge air outlets.

To achieve a true model of such a building, it is crucial to create an accurate representation of the solar radiation passing through the membrane roof and the fitted glass units and of the resulting heat transfer to the room. Another important aspect is the long-wave radiative exchange between the warm inner surfaces of the enclosing walls and the floor surfaces cooled by mechanical cooling systems. The low-e layers on the inner side of the glass units and the membrane roof also need to be taken into account.

This is important for the evaluation of the heat radiation entering the room, which is considerably reduced by the layers, and of the thermal comfort, because the coolness of the floor surfaces is reflected and further lowers the mean temperature of the enclosing surfaces.

A dynamic finite element model of the radiant floor cooling was integrated into the building model so that the time-dependend behaviour of the floor cooling system can also be represented.

Figure 6 Radiant floor cooling system in construction

For the selected floor cooling system (see Fig. 6) the chilled water pipes are arranged at a distance of 150 mm (200 mm in partly shaded areas). They are covered by a 7 cm thick layer of plaster and a 10 cm thick insulation layer beneath. The system is run with a permanent supply temperature of 13 °C and is designed for a maximum cooling capacity of 80 W/m² and a return temperature of 19 °C.

Fig. 7 shows relevant building and system temperatures and their change during the day. With the air displacement system working with a supply air temperature of 18 °C, the air temperature in the occupied areas is maintained at 24 °C as is required, while the air in unconditioned areas above the occupied spaces heats up considerably to temperatures well above the ambient air temperature.

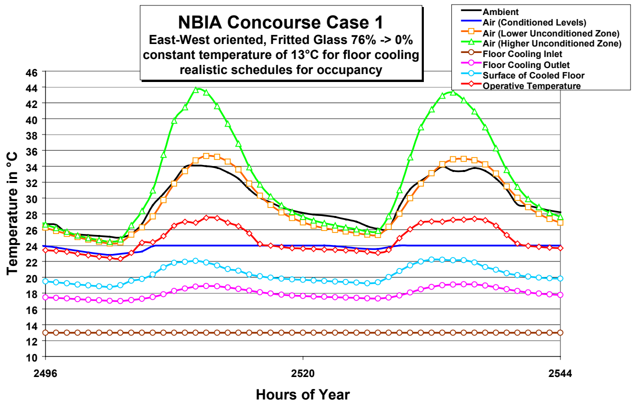

Figure 7 Building and system temperatures of a typical concourse segment in extreme ambient conditions

With convection reduced to minimum by thermal stratification, heat gains by air mixing to the conditioned areas are almost completely prevented. Therefore, thermal insulation of the facade is only of minor importance so that plain glazing with its rather poor parameters in thermal insulation can be used instead of expensive high-quality insulation glass.

The indoor climate is not defined by the air temperature only, but also by long-wave radiation within the room. (Other factors such as humidity and air speed are assumed to be within the comfort range. Occupant activity and clothing levels are given.) For the occupants in the room the building envelope heating up during the day has the same effect as a radiant ceiling heating running at a mean surface temperature of about 55 °C at day peak.

To achieve an acceptable quality of thermal comfort under these circumstances, long-wave radiation has to be minimized. To this end a pyrolytic low-e layer with an emission coefficient of 0.17 is applied to the inner glazed surfaces. This reduces long-wave thermal radiation from the glazed surfaces by 80 %. Furthermore, a transparent PET foil with a metallic low-e coating featuring enhanced resistance to scratching is applied to the membrane roof surfaces to serve the same purpose.

The floor temperature in spaces with radiant floor cooling ranges between 22 °C during the day and 19 °C at night, thus reducing the mean radiative temperature in the room. The floor temperature being reflected from the low-e layers in the roof construction back into the room, affects the mean temperature of the enclosing surfaces accordingly. Adding to this the direct and diffuse solar radiation that hits the occupants, an operative (sensed) temperature is achieved, which can be used in evaluating the thermal comfort of the room.

During the day the maximum operative temperature is slightly above 27 °C. At night the operative temperature is slightly below ambient air temperature, because the envelope cools down to ambient temperature and the room is further cooled by the radiant floor cooling.

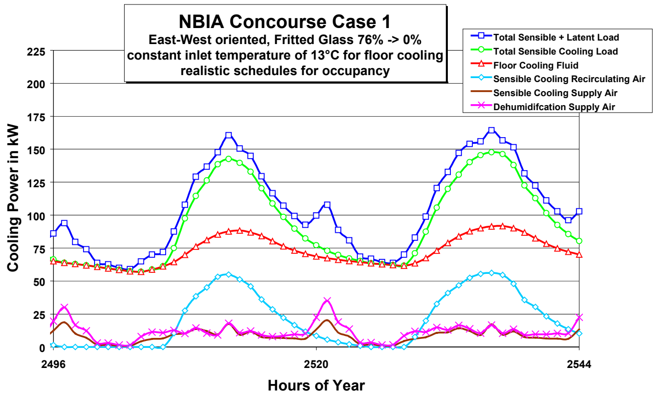

Figure 8 Cooling load for a typical concourse segment in extreme ambient temperatures

Fig. 8 shows the cooling loads to be rejected from the system in a building segment measuring 45 m in width and 27 m in length. The total of sensible and latent cooling loads is 165 kW for this building segment. Transferring this to the building's total occupied surface area of 1,593 m² the cooling load to be rejected amounts to 104 W/m².

The maximum dehumidification capacity for the fresh air required for reasons of hygiene is 35 kW. As most flights in international air traffic are scheduled for the night, maximum room occupancy also happens during the night hours so that only 20 kW add to the peak load at midday. The same applies to sensible cooling of the fresh air down to the supply air temperature.

Cooling capacity of the radiant floor cooling is 90 kW, which is equivalent to about 55 % of the maximum cooling load in the concourse segment. Considering the coverage of the floor surface by chilled water pipes of 68 % the radiant floor cooling has a specific cooling capacity of 83 W/m². This is a fairly high value, which can be achieved with a temperature difference of only 2 Kelvin compared to the ambient, which results from the fact that the radiation heat that hits the floor directly is immediately absorbed by the building component before it is transferred to the air.

The remaining sensible cooling load of 55 kW is covered by the return air share of the air displacement system. In these areas the radiant floor cooling helps reduce the required cooling capacity of the ventilation system to about half of the former value.

If a translucent / transparent building envelope like this one was not optimized, there may be the risk of glare effects and the overall illuminance level may be too high, thus causing disturbance to the occupants.

The aim of optimizing the envelope was to improve its thermal parameters and to adjust daylight incidence into the the building in such a way that artificial lighting is not required during daytime even with overcast skies and that at the same time the overall illuminance is reduced so that no glare effects occur.

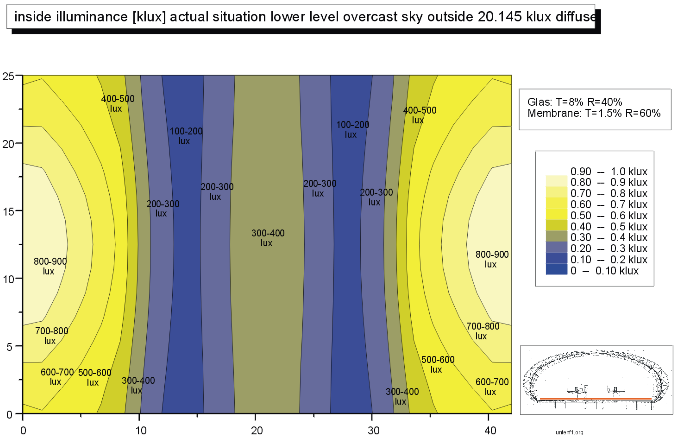

Figure 9 Illuminance on the lower level of a typical concourse segment with overcast skies

The solution is the reduction of daylight transmission through the membrane roof sections by applying additional sound insulation layers and reducing the ceramic frit density on the glazed parts from 75 % at the top of the roof to zero on the walls.

The facade structure was optimized with regard to daylight transmission based on the results of detailed daylight simulations carried out with the SUPERLITE (2) and RADIANCE (3) programs in combination with the thermal simulations.

Fig. 9 shows the illuminance of the occupied areas on the lower level for an overcast sky in Bangkok. The distribution of illuminance is determined by the envelope structure with an increasing share of glazed surfaces in the side walls. With light transmission rates of 2 % through membrane sections and 7.5 % through glass sections with a maximum ceramic frit densitiy an even distribution of illuminance is achieved, while only a small area between the supports of the upper level shows a daylight illuminance of less than 300 lux, which is the minimum value for a working place. Daylight simulations proved that the target requirement to be able to go without artificial lighting even on days with overcast sky can be met.

The major precondition for the feasability of the whole energy concept is the forming of a stable thermal stratification in the areas without air conditioning, which are situated above the air conditioned areas. It is crucial to safeguard that the thermal stratification cannot be distroyed by convection of warm air along the heated facade or by other disturbances from the lower level, and to know how long it takes the stratification to form in the morning and what happens when the facade cools down in the evening.

To find out about this and to verify the approach to air movements between the areas with and without air conditioning, extensive fluid-dynamic simulations accompanied the thermal evaluation of the concept. Several different concourse segments were examined and transient calculations were carried out to determine the stratification and de-stratification processes in the morning and in the evening.

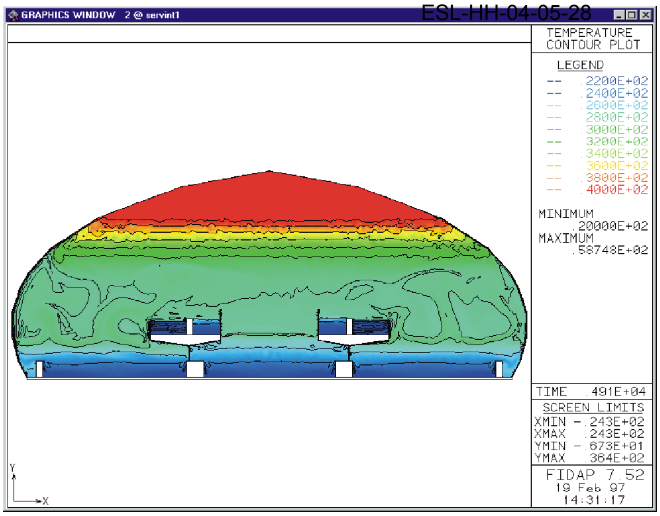

Figure 10 Distribution of air temperatures in a typical concourse segment during the day

These calculations were processed by the CFD program FIDAP (4), which allows the user to create a perfect image of the long-wave radiative exchange between the surfaces within a room.

Starting from the night time situation with an ambient air temperature of 25 °C and a homogeneous air temperature of 25 °C across the whole indoor air volume, the outdoor temperature in the CFD simulation was raised to 34 °C and a solar radiation of 900 W/m² and the maximum internal heat loads resulting from occupants and equipment were added. A floor surface temperature of 22 °C as determined in thermal simulation, and a supply air temperature of 18 °C from the air displacement system were used for calculations.

Transient fluid simulations examined the change in structure of the thermal stratification over the course of time. The distribution of temperatures in the examined concourse segments 80 minutes after switching on the day time conditions are shown in Fig. 9. In the occupied areas of the lower level and in the corridors on the upper level, a lake of cool air from the displacement system with a temperature of 22 to 24 °C has formed and stays stable over the whole day.

Only some metres above these areas, the air temperature rises quickly to about 30 °C. Directly under the roof a temperature of 55 °C is reached. The maximum temperatures of the glazing and the membrane roof construction can be as high as 60 °C.

The stratification of the indoor air stays stable despite convection resulting from air rising at the glazed facade. Even the overspill of cool air from the multi-level corridors over the glass balustrades does not destroy the thermal stratification. In comparable scenarios without any floor cooling system the floor surface temperature rises to 30 °C and completely destroys the intended thermal stratification. Due to convection the whole air volume is being mixed so that minimizing the air volume to be cooled is no longer possible and the cooling demand rises considerably.

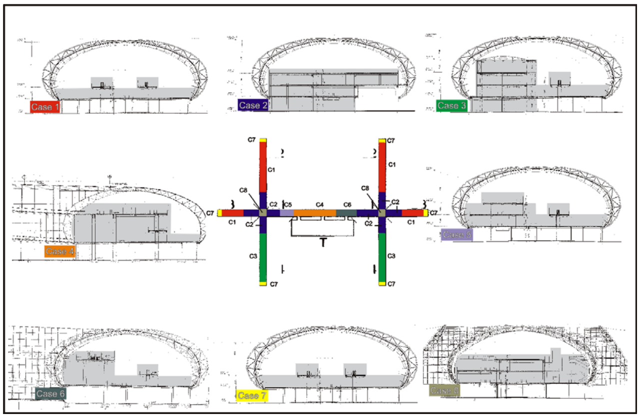

Figure 11 Segmentation of concourses into typical zones to determine the total cooling demand of the building

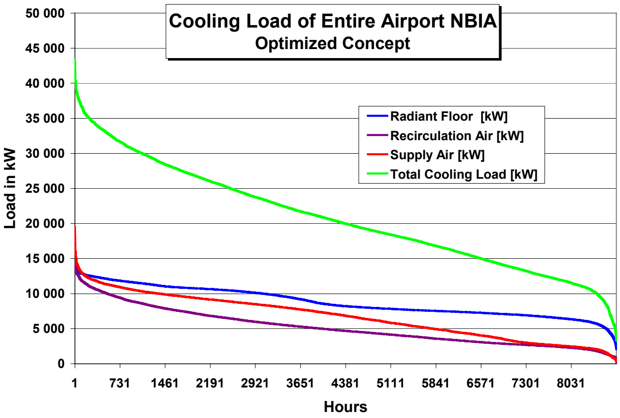

Figure 12 Annual change in cooling demand of the building for the optimized building concept

To determine the cooling demand for the whole airport, the whole building complex is segmented into several representative zones. The terminal building was segmented into its 6 occupied levels, and the concourses were segmented into zones of typical cross-sectional structures and for different purposes, and all zones were processed in thermal simulation.

Fig. 11 shows the typical concourse segements that were examined and their occurrence in the building complex. Figures on a grey background show the respective conditioned air volume. The total dynamic cooling demand of the airport was determined by analysis of these results in the correct sequence in time.

Fig. 12 shows a graph of the annual change in cooling demand for the whole airport as well as the share for the radiant floor cooling, fresh air cooling and dehumidification and the return air for the ventilation system according to the optimized building concept. In this diagram maximum passenger occupation of the airport was moved to midday with maximum solar radiation, to show that the concept will work even if flight schedules are drastically changed**.**

The building has a maximum cooling demand of 44 MW, where a third is covered by radiant floor cooling, fresh air conditioning and return air cooling respectively. With pre-cooling of aircrafts and jetbridges added the maximum demand amounts to 50.5 MW. Transferred to an air conditioned occupied surface area of about 375,000 m², the specific cooling demand is 135 W/m².

Optimizing the building envelope and adjusting the cooling system (base line: mixed air-only cooling concept) helped reduce the total cooling demand of 77 MW or 205 W/m² in the starting situation by about 35 %. Although energy input was reduced, the thermal comfort for the occupants of the airport was considerably improved.

The annual energy demand for the cooling system amounts to 191 GWh/a, which is equivalent to 513 kWh/m²a for the occupied area. The share of heat covered by the radiant floor cooling is about 40 %.

Energy demand is reduced by about 84 GWh/a compared to the starting situation, which is equivalent to a reduction by about 30 %.

MATERIAL DEVELOPMENTS AND CONCEPT ANALYSIS BY MEASUREMENTS

To achieve thermal comfort in a transparent building in the extreme climate of Thailand, the building envelope needs to be perfectly optimized.

In cooperation with our partners in industry, the findings from the simulation processes were used to develop practical solutions to achieve the required optical and energetical parameters in the glass structure.

Fig. 13 shows the structure of optimized laminated glass. There is an 8 mm thick clear tempered safety glass pane with a double-fritt pattern of ceramic frit on the inner surface with white dots to the outer and black dots to the inner space in densities of 75 %, 65 %, 55 %, 37 % and 20 % down to zero. The ceramic frit layer is followed by a highly selective and anti-reflective sun protection coating and a 6 mm thick heat strengthened clear glass pane with a pyrolytic low-e coating on the inner surface.

This structure shows transmission rates of 30 % in the visible region and 15 % in the solar spectrum for glass sections without ceramic frit, although the light reflection rate of such panes is not higher than that of uncoated glazing.

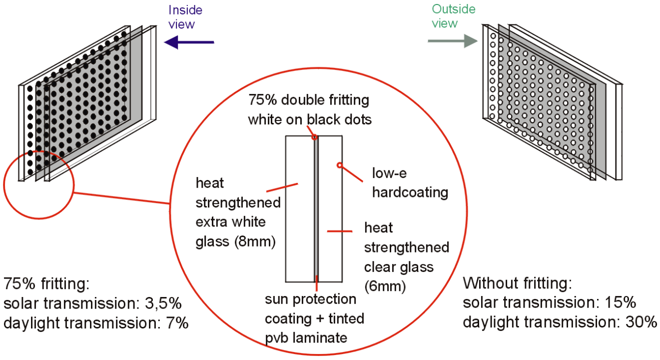

Figure 13 Structure of optimized glazing

The black frit pattern on the inner surface when looked at from a certain distance in the building creates an optical effect that is similar to that of wearing sun glasses: there is a clear undisturbed view from inside to the outside, but the brightness is reduced. This effect is facilitated by the ability of the human eye to supply the missing information in the image. Fig. 14 shows the view through glazing with a high ceramic frit density in a test building.

Figure 14 Testing glazings with different densities of ceramic frit

The membrane roof construction was also put into practice in this test building. The optimized transparent sound absorbing layer, which was developed specifically for this project, is installed directly under a 1 mm thick glass fiber PTFE membrane functioning as an enclosure and weather protection for the building. On the inner side of the roof is a thin transparent foil with a low-e coating on its inner surface. For reasons of statics the foil is applied to a perforated membrane, which lets the internal sound pass. Daylight transmission rates of about 2 % through the translucent membrane roof were proved by measurements with a coefficient of thermal conductance of 2.5 W/m²K.

The upper part of Fig. 14 shows the membrane roof. Although light transmission rates are low, the combination of membrane construction and glazing helped achieve a building that is bright with daylight.

ANALYSIS OF THERMAL STRATIFICATION

The crucial step in verifying if the energy concept is feasible in practice was to prove by experiment that the thermal stratification is really formed as predicted by fluid simulations.

Figure 15 Measuring indoor air movements in an indoor tennis hall, experimental setting

Figure 16 Verification of the forming of a stable thermal stratification by a smoke test

In summer, indoor air movements were measured in an indoor tennis hall having translucent membrane roof and an air conditioning concept similar to that of the project. With a length of 37 m, a width of 18 m and a height of 7 m the tennis hall is comparable to the concourse segments in a scale of 1:3. In the experimental setting shown in Fig. 15 the lower part of the hall is supplied with cooled supply air from the ventilation system with discharge air being removed via an air discharge, which is variable in height. Thus, no air conditioning is applied in the upper part of the hall.

During a summer period with high ambient temperatures the system was run with parameters similar to those of the planned energy concept. The occupied area was cooled down to a temperature of 24 °C by air conditioning and the floor was kept humid and cool, while temperatures in the upper parts reached 30 °C.

Fig. 16 shows that the smoke test proves the forming of a stable stratification.

The injection of smoke into the air conditioned and permanently exchanged air volume up to a height of 2.4 m on the one hand, and into the heated air volume with stable stratification directly below the roof of the hall results in the forming of a smoke-free layer between the two air zones. This layer stayed stable despite a temperature gradient that was smaller than under real conditions and was not even disturbed by the ventilation system or occupants.

This experiment proves that the fluid simulations provided correct results and that the energy concept will definitely function in reality.

The measurements taken in the experimental setting show that the verification of a complex concept requires not only the use of a wide range of simulation technologies, but also the support for concept suggestions by experimental measurements.

ENERGY SUPPLY CONCEPT

After optimizing the energy demand of the building, the energy supply for the building had to be considered, and several concepts for energy supply were compared. The existing supply concept for the new airport comprises a chilled water network with system temperatures of 6 / 12 °C and chilled water generation by an electrically powered compression chiller system.

This concept was compared with a co-generation concept using gas turbines on the one hand, and another concept using absorption chiller systems on the other hand. For both concepts the effect of using a chilled water storage tank with a capacity of 285 MWh to level out the changes in cooling demand over the course of the day was examined. It showed that the chilled water storage is usefull to cut cooling peaks (investment cost) and reduce energy cost (due to lower off peak electricity cost) whereas the cooling energy demand is hardly changed.

Furthermore, the use of highly efficient solar collectors covering a surface area of 35,000 m² in combination with an absorption chiller system and gas heating as a back-up system was examined. Under climatic conditions as in Thailand with high solar radiation, high-efficiency evacuated tube collectors with CPC reflectors can be used to generate a temperature of 190 °C required for the operation of a double-effect absorption chiller system.

A concept using photovoltaic modules covering a surface area of 55,000 m² for the immediate generation of electric power in combination with an electrically powered compression chiller system was compared to other concepts under the aspect of economy. Fig. 17 shows the investment costs for severel different concepts.

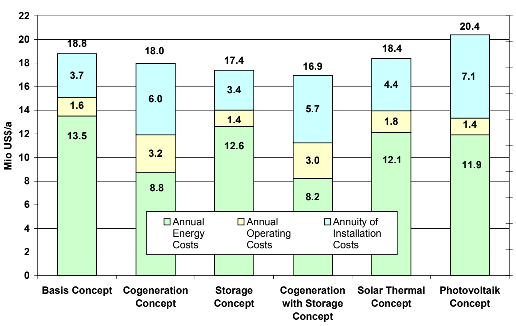

Figure 17 Investment costs for several energy supply concepts

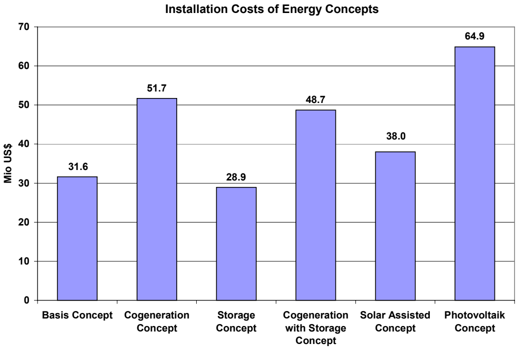

Figure 18 Total annual costs for several energy supply concepts

The total annual costs including not only the investment costs broken down to an annual value, but also the energy and operational costs for the system show that the integration of a storage tank reduces the investment costs because of a decrease in cooling demand and annual regular costs.

The co-generation concept in combination with a storage tank accounts for the least annual costs. It is remarkable that the thermal use of solar energy produces less annual costs than the conventional concept.

To evaluate the different concepts under the aspect of ecology, the concept using regenerative solar energy and the approach for an efficient use of energy by co-generation were compared to the conventional concept using an electrically powered vapour compression chiller system in combination with a storage tank.

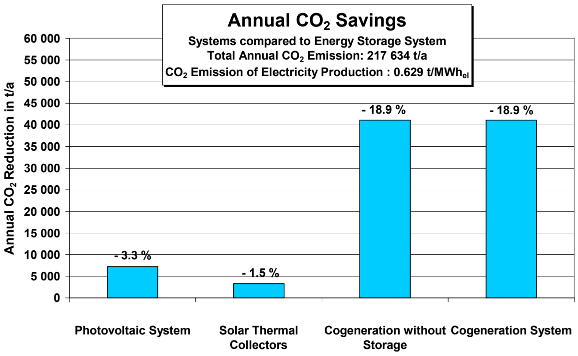

Figure 19 CO_2 reduction potential for several energy supply concepts

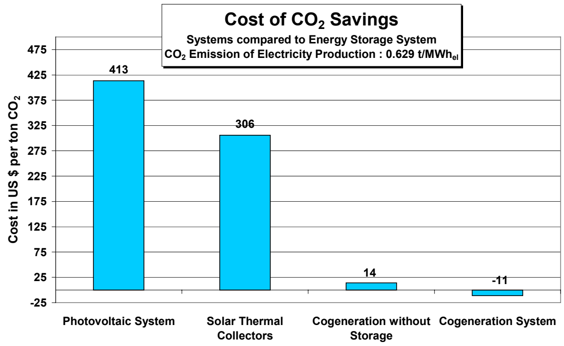

Figure 20 Specific costs for the reduction of CO_2 emissions for several energy supply concepts

Fig. 19 shows that with the determined specific CO_2 emissions for power production in Thailand, co-generation of power and refrigeration achieves considerably higher reductions in CO_2 emissions than the use of solar energy.

When the total annual reduction in CO_2 emissions is divided by the additional annual costs for each system, the result are the specific costs for reducing emissions by one tonne of CO_2 (see Fig. 20).

For the co-generation concept, costs for the reduction of CO_2 emissions are very low, or even negative if the storage tank is used, which means that this concept provides the required amount of energy at lower costs than the other concept. As a consequence, this energy supply concept featuring very favourable ecological parameters is strongly recommended for the airport.

For additional investment costs energy contractors can provide preliminary financing without charges for the constructor.

This study shows that not only under the aspect of investment costs, but also with regard to costs for environmentally friendly systems, optimized innovative concepts using thermal solar collectors should be given preference over systems using photovoltaics technology.

DESIGN - TEAM

Architects:	Murphy / Jahn Architects, Chicago
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Energy, comfort:	Transsolar Energietechnik GmbH, Stuttgart
HVAC engineers:	Flack+Kurtz Consulting Engineers San Franscisco
Acoustics:	Laboratorium für Optik und Dynamik, Dr. R. Blum, Leonberg

SIMULATION PROGRAMS USED FOR ANALYSIS

(1) TRNSYS 14.2, A Transient System Simulation Program, Solar Energy Laboratory, University of Wisconsin, Madison, U.S.A. 1996

(2) SUPERLITE, Adeline 2.0 IEA Solar Heating and Cooling Program ,Task 12

(3) RADIANCE , Lighting Systems Research Group, Lawrence Berkeley Laboratory

(4) FIDAP 7.52, Fluid Dynamics International, Evanston, Illinois, U.S.A.