ENERGY MODELING OF A HIGH PERFORMANCE BUILDING IN THE U.A.E. FOR SUSTAINABILITY CERTIFICATION

Marcus Jones[1], Stephan Ledinger[2]
[1]Technical University of Vienna, Vienna, Austria
[2]Austrian Institute of Technology, Vienna, Austria

ABSTRACT

The Sheikh Zayed Desert Learning Centre (SZDLC) is a high performance sustainable exhibition center under construction in the U.A.E, aiming for the highest achievable sustainability ratings within the LEED and Estidama sustainability building rating programs.

The Leadership in Energy and Environmental Design (LEED) sustainable building program provides a set of criteria for rating sustainable buildings (U.S. Green Building Council 2009). The Estidama rating program, currently in its pilot phase, is an upcoming sustainable building guideline for the Emirate of Abu Dhabi (Urban Planning Council, Abu Dhabi 2008). The Estidama program is similar to LEED in many ways, with a focus on the integrative design process for sustainable building projects.

Both of these rating programs assign a large share of points to reducing energy usage which is related to CO_2 production. To demonstrate that a design has improved performance, the rating programs encourage the use of whole building energy simulation. The building as it is designed is simulated and compared to a baseline building, where the building envelope and systems are replaced with materials and components meeting minimum acceptable standards. The percentage improvement of the As-Designed building over the Baseline building dictates the number of points awarded in the respective categories.

Innovative solutions in managing the simulation complexity and visualizing energy performance were necessitated by the complexity of performing the building simulations. Improved decision support during the design phase and a better understanding of energy usage in the building are expected to improve the energy efficiency, operating costs, and environmental impact of the building. The detail available from an ambitious modeling approach is presented, demonstrating the usefulness of building energy performance simulation for sustainability ratings as well as design decision support.

CERTIFICATION PROGRAMS

The Leadership in Energy and Environmental Design program, administered by the U.S. Green Building Council, was introduced in 1993 and has undergone many revisions. LEED is widespread, with estimates stating that 20,000 projects in various phases exist worldwide. LEED is a green building certification system encompassing sustainability concepts of energy savings, water efficiency, CO2 emissions reduction, improved indoor environmental quality, and stewardship of resources.

Estidama was released to the public in April of 2010 as a program with many similarities to LEED. However, important differences exist, both based on lessons learned from LEED and other sustainability initiatives and considering the unique sustainability concerns in the U.A.E. In (Elgendy 2010), the author compares the three sustainability programs of Estidama, LEED, and BREEAM (a sustainability program in the United Kingdom). The author cites key differences such as a greater emphasis on water conservation and Estidama's emphasis on the Integrated Design process (IDP) which encourages design coordination at the early stages of the project. Another key difference is Estidama's planned integration integration into the Abu Dhabi development codes, unlike the purely voluntary LEED program.

BUILDING CONCEPT AND MODELING

Modeling

The simulation tool used to analyze the energy performance of the Sheikh Zayed Desert Learning Centre is TRNSYS version 16.01 (Solar Energy Laboratory, Univ. of Wisconsin-Madison 2004). TRNSYS is a dynamic simulation platform for simulating systems over time periods from days to years at time-steps of seconds to hours. TRNSYS meets the requirements for LEED certification of energy performance through the whole building simulation method of EA Credit 1.

TRNSYS is capable of modeling detailed energy performance systems including complex building geometry and a large number of individual HVAC components and subsystems. TRNSYS is flexible and customizable. For the scientific analysis of the Sheikh Zayed Desert Learning Centre over 400 individual TRNSYS components were specified and connected in one large simulation. The time step, or resolution of the simulation, was set at 5 minutes to capture the detailed dynamic behavior of the system.

Because of the level of detail to which the Sheikh Zayed Desert Learning Centre was modeled, a new platform for analyzing and organizing simulation data was developed in the technical computing platform Matlab. By importing data from TRNSYS into Matlab, a higher level of detail and quality control was facilitated. Details of the implementation of the TRNSYS model, the Matlab processing, and the general methodology of the simulation can be found in several upcoming scientific publications (Jones and Ledinger 2010a; Jones and Ledinger 2010b).

The Sheikh Zayed Desert Learning Centre is designed as a building with improved energy performance to meet certification requirements under sustainability programs, to reduce life cycle costs and environmental impact, and to be a flagship sustainable building in the U.A.E. The number of renewable energy features and systems makes the building energy performance analysis complex to model and analyze. Challenging features of the Sheikh Zayed Desert Learning Centre include;

- Thermally massive building envelope
- Complex shape of building and thermal zones
- Large and complex HVAC network
- Concrete core activation for cooling
- Solar thermal absorption cooling
- Fresh air pre-cooling using a soil-air heat exchanger
- Air exhaust enthalpy recovery
- Electricity generation by photovoltaic array

Envelope

The Sheikh Zayed Desert Learning Centre represents a massive building construction with a highly insulated outside shell. The complex geometry of the building, figure 1, contains mainly exhibition areas. The exhibition space expands from above the basement through the curved main construction to the top of the building. Excepting the theatre and restrooms, this exhibition space represents one air volume without partitions. A special zone of the building is the funnel, which is designed to connect all the different levels of this exhibition space, and which contains a water pond at its base. The basement houses the mechanical equipment and is interfaced to all levels of the building through vertical riser shafts. The heat rejection for the HVAC system is located on the roof of the building above the exhibition zones.

The complex geometry of the building requires an abstraction to derive an appropriate thermodynamic representation from the architectural model. Therefore, the structure is divided into thermal zones, which partly represent actual zones of the building (Entrance, Offices, Toilets, Theatre, ...). Due to the exhibition area being an open space expanding from the bottom to the top level of the building, this part of the building was sub-divided into smaller zones in order to represent the actual thermal behavior with greater accuracy. The thermal zones of the building model are presented in figure 2.

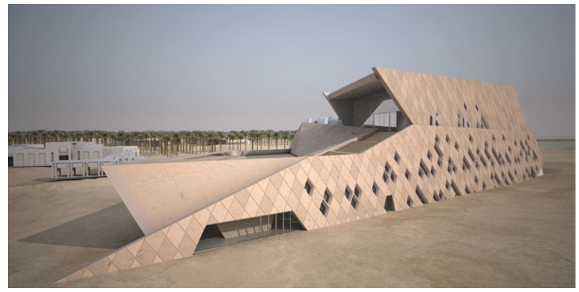

Figure 1: Architectural concept

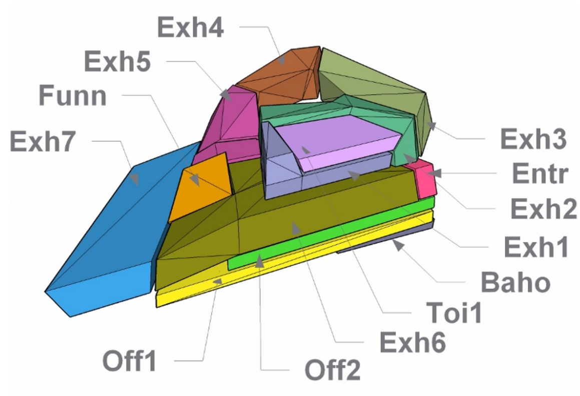

Figure 2: Thermodynamic zoning - Front view

Systems

The heating, ventilation, and air-conditioning system is divided into two major systems. The air-side system provides fresh air for occupants, and the water-side system supplies chilled and heated water to the air-side system in order to condition the supply air.

An overview of the air-side system is shown in figure 3. The air-side system was divided into five major sub-systems. The soil-air pre-cooling subsystem contains the total fresh air intake for the building. The maximum rated fresh air flow rate for the building is $63000\,\mathrm{m}^3/\mathrm{hr}$, or $52500\,\mathrm{kg}/\mathrm{hr}$. The instantaneous fresh air flow rate is regulated by the current occupancy level of the building. The soil-air pre-cooling system is designed to cool the fresh air using the cooler earth temperature.

The water side system is composed of elements as displayed in figure 4. Three chillers operate to meet the chilled water cooling demands of the air side system and the concrete core activation network. Two conventional vapor compression chillers are designed to meet the temperature set points required for sensible and latent cooling of the moist air stream for comfort conditions. A solar absorption cooling subsystem is also designed to meet some of the demand by the concrete core activation network.

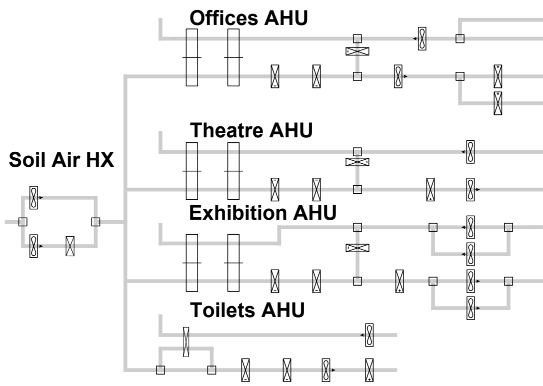

Figure 3: Scheme - General - Air side system

Each of these three chillers must be supplied by cooling water, provided by 6 cooling towers. Optionally, the cooling water is first used to reheat the supply air streams. The chilled water loads are the concrete core network, the four stage-one cooling coils, four stage-two cooling coils, 3 mixing air stream cooling coils, and local cooling.

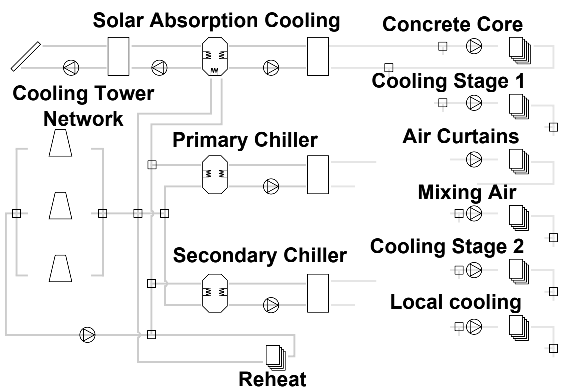

Figure 4: Scheme - General - Water side system

RESULTS

A benefit of taking such a detailed approach to energy modeling is the quality of understanding and analysis generated from the model. Time series plots of any resolution are possible to answer detailed questions of performance. State-diagrams of any instant in time are also generated to understand the entire system under any conditions. Examples are presented in the following subsections.

Air set-points

The zone air temperature is plotted over the simulation year in figure 5. All four classes of thermal zone; exhibition, offices, theatre, and sanitation, reach the set point conditions of 25 °C and 10 g/kg. Figure 6 is a state diagram of the entire air system for noon, on July 15th. This diagram is automatically generated from the simulation data (see (Jones and Ledinger 2010b) for details), providing key performance information to the simulation team, design team, or client.

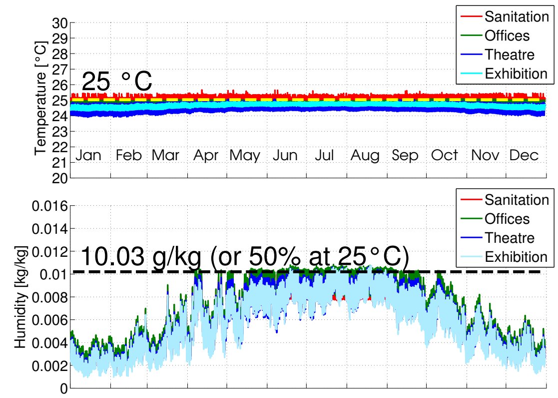

Figure 5: Annual performance - Zone air temperature and humidity

Solar cooling system

Figure 7 shows the performance of the absorption cooling system over a summer day. The incident radiation peaks at $905\,\mathrm{W/m^2}$ on the horizontal at noon. This corresponds to the peak collector temperature of 98 °C (red line). The collector field raises the temperature of the primary loop water by 7 °C. This heating water is stored in the hot storage tank and sent to the absorption chiller. The cooling water (purple line) is pumped through the condenser and absorber of the chiller at a set-point of 28 °C. The chiller operates when the storage tank is able to provide hot water above 95 °C. The chiller then continues to operate unless the heating water falls below 75 °C. The chiller operates on an on-off control strategy with hysteresis.

Annual energy performance

Two air set-points are considered in the design of the Sheikh Zayed Desert Learning Centre; one mode aims for interior air thermal comfort conditions of 25 °C at 50 % relative humidity ($10.03\,\mathrm{g_{moisture}/kg_{air}}$), the other mode aims for 23 °C at 40 % relative humidity ($7.20\,\mathrm{g_{moisture}/kg_{air}}$). These two set-points will be considered as the high set-point and low set-point respectively.

The implication of these two set-points is considered in figure 8. Two simulations were performed, one with the high set-point, and one with the low set-point, each set-point being maintained for the entire year. Figure 8 displays the annual energy consumption of the HVAC system

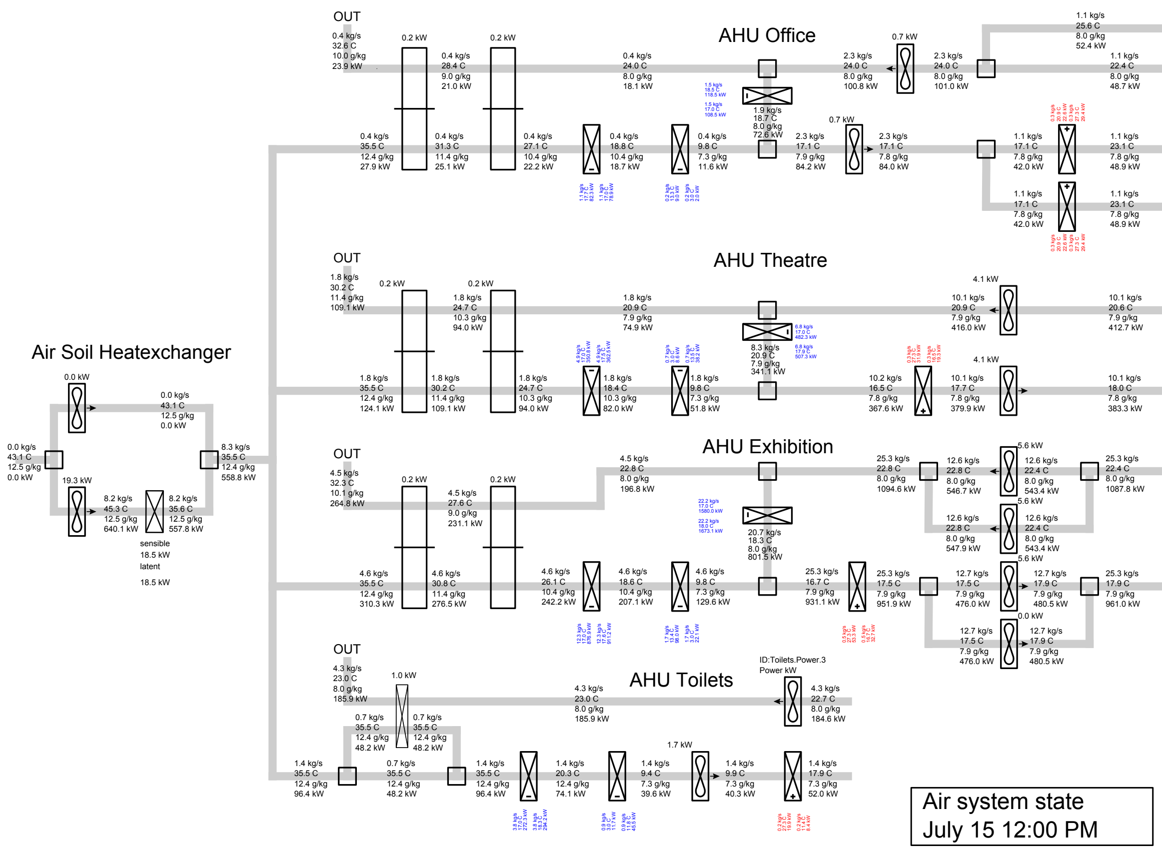

Figure 6: Computer generated air side state diagram

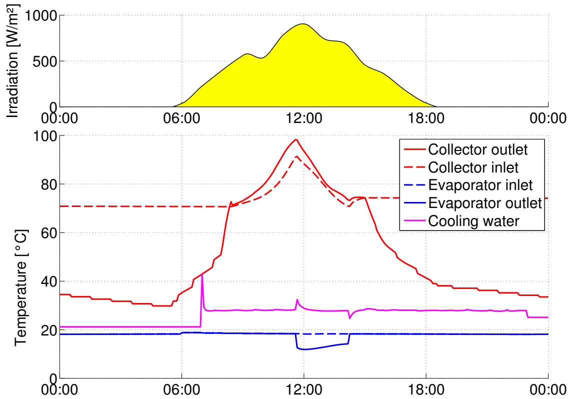

Figure 7: Single day performance - Solar cooling

of the Sheikh Zayed Desert Learning Centre for these two set-points.

Table 1 details the annual energy consumption of the 5 simulations performed for LEED certification within Energy and Atmosphere Credit 1, using Option 1 - Whole Building Simulation. All numbers are in units of MWh of electrical energy consumed per year. The As-Designed building (AD) as simulated consumes a total of 2223 MWh of electrical energy to operate. The Baseline building (BL) is first simulated according to the original orientation of the As-Designed building, and then rotated three times by 90. This rotation is designed to eliminate the effect of a favorable or unfavorable orientation according to the local shading and irradiation conditions. Because the Sheikh Zayed Desert Learning Centre is minimally glazed, and because the glazing is distributed evenly across all walls for the Baseline building, the effect of rotating the building on the overall energy consumption is minimal. The average energy consumption of the Baseline building is 3115 MWh.

The information in table 1 is displayed in figure 9 summarizing the annual electrical energy consumption of the Sheikh Zayed Desert Learning Centre according to categories prescribed by the LEED NC v2.2 certification program. Both the As-Designed simulated and the Baseline simulated annual energy performance are displayed.

Peak electricity demand behavior

To summarize the electricity consumption peak behavior, a load duration curve is generated in figure 10. Figure 10 is a histogram of the total electricity consumption (the load imposed by the building on the grid), counting the number of periods each load level occurs throughout the year. The period size is 5 minutes, reflecting the simulation resolution. The load levels (histogram bins) are at 1 kW increments. Integrating the load curve results in the total annual building load, 2223 MWh.

Table 1: LEED category annual energy consumption

	Design	Baseline
Interior Lighting	545	545
Exterior Lighting	11	11
Space Heating	0	0
Space Cooling	416	1043
Pumps	186	179
Heat Rejection	153	204
Interior Fans	297	486
Parking Garage Fans	0	0
Service Water Heating	0	32
Receptacle Equipment	409	409
Interior Process Lighting	0	0
Refrigeration	9	9
Data Centre Equipment	166	166
Cooking	9	9
Elevators and Escalators	24	24
Sum [MWh]	**2223**	**3115**

Conclusions to be drawn from figure 10 are outlined in three regions. Simulation results indicate that the building will have a baseload outside of occupation hours between 0 and 100 kW. When the building is operating with no major cooling demand, the occupational baseload during the day is between 100 and 300 kW. The remaining peak load occurs during the summer months when significant cooling is required. This peak load is in the region of 300 and 600 kW.

Further detail of this peak behavior is illustrated in figure 11, which shows a single day, July 20th. The peak electricity consumption occurs in the late afternoon and early evening. The power consumption for each class of electrical consumer is plotted over the day. The power consumers which have the largest influence on the peak electricity of the Sheikh Zayed Desert Learning Centre are related to the space cooling demand. Related to the conventional chillers is the heat rejection system, which tracks the peak behavior of the conventional chillers. The y-axis represents the electrical consumption of all systems, in kilowatts. Each system contributes to the total electrical consumption. The maximum peak power consumption of the Sheikh Zayed Desert Learning Centre can therefore be estimated at 600 kW during the late afternoon.

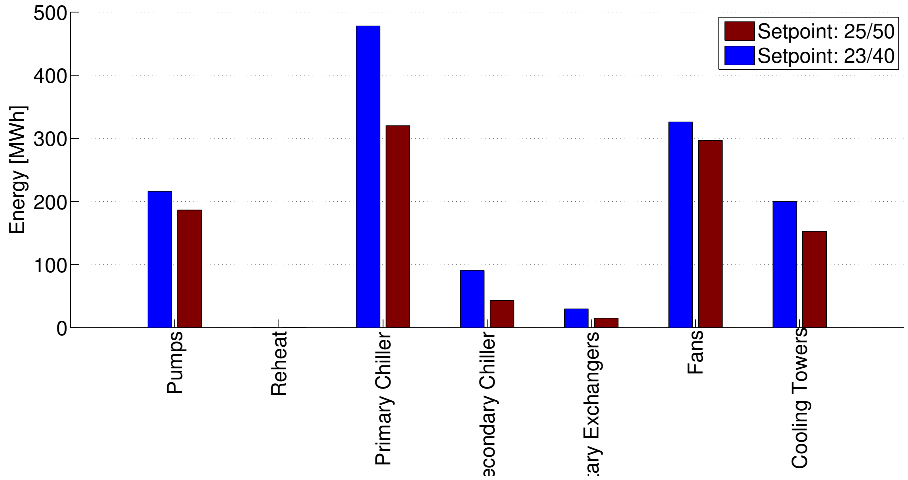

Figure 8: Comparison - 25/50 and 23/40 air condition set points

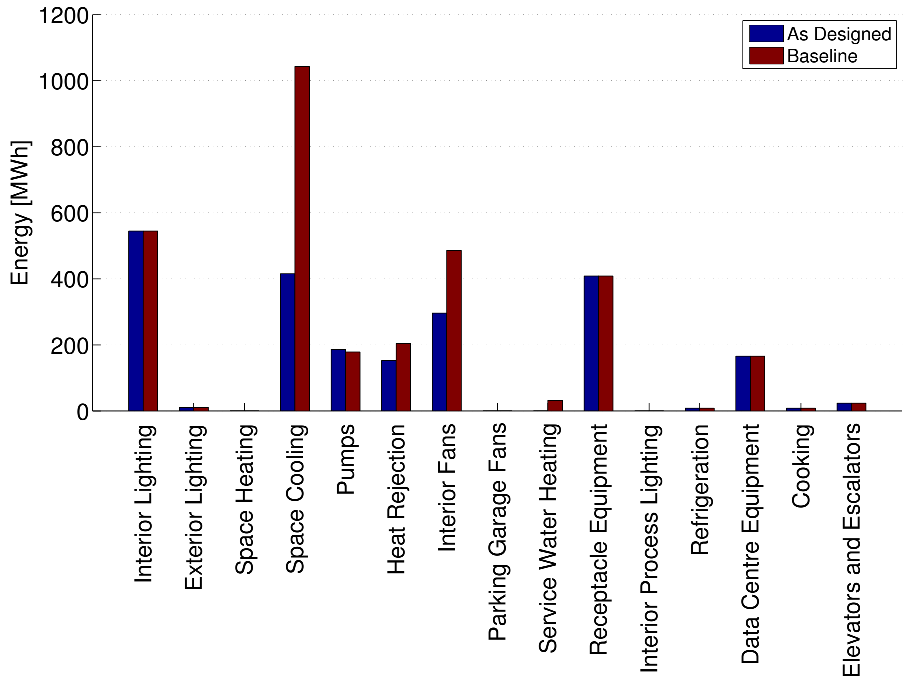

Figure 9: Comparison - Total annual building energy performance

The average Baseline annual energy consumption is 3115 MWh, and 2223 MWh for the As-Designed . In addition to this energy savings, the As-Designed building produces an additional 236 MWh of electrical energy using the PV array. Therefore, the percentage increase in energy performance over an equivalent building meeting a minumum energy efficiency standard in both envelope and system is;

$$\text{Improvement} = \frac{(\text{Baseline Energy} - \text{Proposed Energy})}{\text{Baseline Energy}}$$

$$\text{Improvement} = \frac{3115 - (2223 - 236)}{3115}$$

$$\text{Improvement} = 36.2\%$$

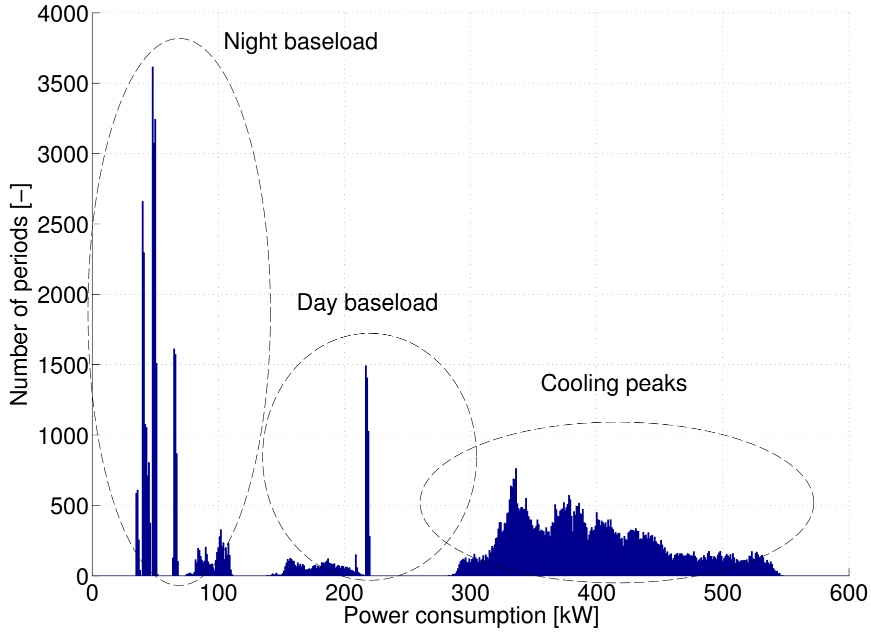

Figure 10: Load curve - Total building demand

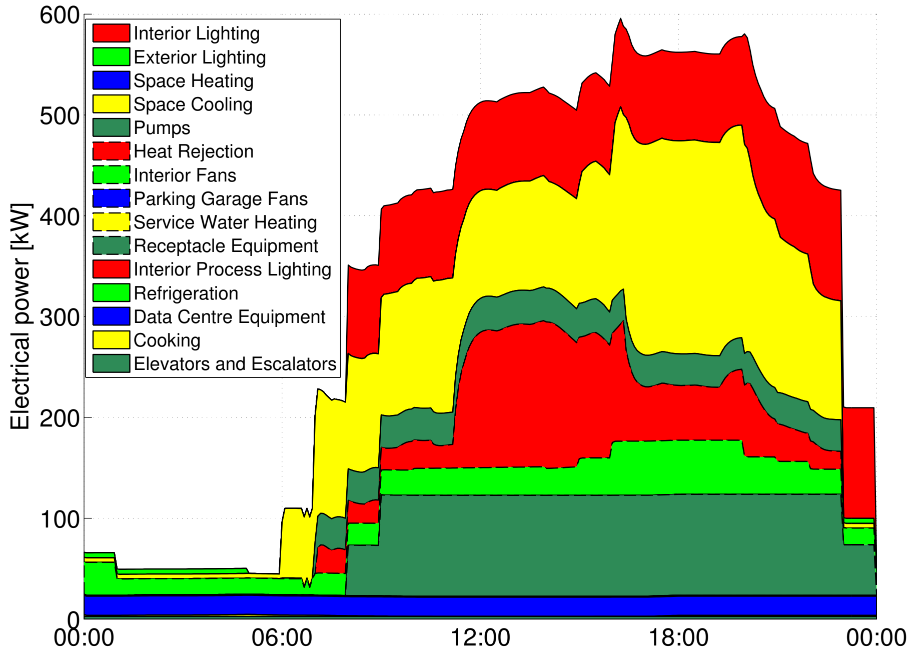

Figure 11: Peak analysis - July 20th peak load

CONCLUSIONS

The complexity of simulating an advanced exhibition center with ambitious sustainability goals in Al Ain, U.A.E., necessitated the development of new methods and techniques. The simulation tool TRNSYS 16 was used to model and simulate the energy performance of the as-designed building, to provide scientific support and to fulfill modeling requirements for certification. Without these methods and techniques, the complexity of the system and building would be overwhelming. Using these methods, the system and building could be analyzed for certification requirements with greater detail and speed. Time plots and state diagrams of systems can be generated providing new ways of thinking about energy performance. Energy performance figures, such as annual consumption or load curves, can be quickly aggregated and optimized.

The role of energy simulation in the building industry is becoming known to practitioners, as simulation tools become more capable and pressure to create sustainable high performance buildings increases. As the sustainability certification programs find their way into building standards and new ways of handling archecture projects such as the Integrated Design Process become more accepted, simulation will play a key role in providing data to the design team in order to understand trade-offs and variants to ultimately make well informed decisions.

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