OPTIMIZATION MEASURES FOR SPORTING AND SPECIAL EVENT FACILITIES: DESIGN AND OPERATION

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ABSTRACT

Reducing unnecessary building energy costs is becoming more of a priority. Rising fuel prices and a global emphasis on energy efficiency are key contributing factors. This push towards energy efficiency certainly applies to today's athletic and special event facilities. High customer expectations and corresponding large operating expenses have helped to make energy conservation measures more of a priority in the facilities design. The heating, ventilation, and air conditioning (HVAC) systems in sporting and special event facility present a unique challenge to Continuous Commissioning (CC) engineers. In such facilities, high occupancy and equipment loads occur at the design load condition, but only a small fraction of the designed capacity is necessary for routine operations. On the other hand, during games and other events, system performance is critical. Therefore, significant savings potential exists, but care must be taken to avoid compromising the peak load operations. Maintenance uncertainties, equipment wear, and lack of operator knowledge all combine to affect the building operating costs. Continuous Commissioning, a process developed by the Texas A&M Energy Systems Laboratory, addresses issues such as these and proves very worthwhile [1,2]. An overview of multi-purpose arenas and their usage will be given, and potential optimization measures and Continuous Commissioning of these facilities will be presented, along with some illustrative examples.

INTRODUCTION

Today's sports world has been revolutionized by the entertainment industry. This has drastically affected the design and operation of modern sports facilities. The facilities of yesterday often were solely used for sports events, had poor heating and ventilation, and were not air-conditioned. The buildings consisted of little more than the spectator seating, main playing floor, and the team locker rooms. Such facilities are no longer considered marketable. In terms of overall design, technological systems, and functional use, modern multi-purpose arenas only vaguely resemble those of 50 or so years ago [3]. Consumer and industry standards have changed and today's arenas are typically characterized by private luxury suites, closed circuit television, large video and scoreboard displays, varieties of restaurants and concessions, and large banquet facilities [4]. TV studios and production offices, ticket offices, facility and team offices, practice courts, and team stores are common as well [3]. In addition to serving as an athletic facility, modern multi-purpose arenas are used for banquets, conferences, trade shows, concerts, circuses, and a host of other functions [3]. Air conditioning and proper ventilation is considered mandatory, and there is often some form of carbon dioxide (CO_2) monitoring [3,6]. These are most often incorporated into the facilities energy management system (EMCS).

The HVAC systems for such facilities are characterized by large air handling units (AHU) serving the arena bowl and spectator seating area and an assortment of smaller units serving the concourses, practice court, locker rooms, banquet areas, luxury boxes, offices and so on. Figure 1, on the following page, provides a general diagram. Building construction and

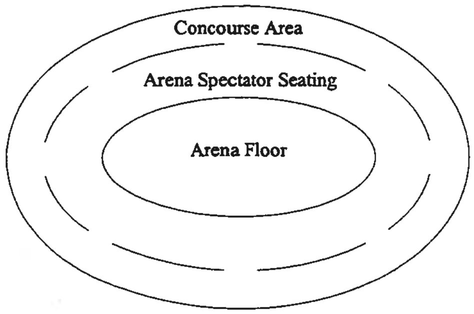

Figure 1. General Arena Illustration

space limitations can often dictate the type of system installed. Locker rooms are usually served by constant volume reheat systems because, when in use, the system can exhaust up to 90% of the supply air [3]. This is due to the nature of the facilities and equipment, and is essential to avoid high humidity conditions and odor problems. The large arena AHUs are usually housed within the roof structure, and consist of a constant volume supply fan, constant volume return fan, preheat coil, cooling coil, filters, the necessary relief and mixing dampers, and sometimes heat recovery equipment [3]. Additionally, the arena units are designed to control space humidity as well as temperature, and may have face bypass dampers along with reheat coils. Reheat is needed for the AHUs to function adequately during high humidity and low load conditions. Overhead ducting, long throw diffusers, and the fan assisted return air system ensure adequate air movement [3]. The concourse units are actually part of the arena HVAC system, as the arena return air is typically drawn through the concourse areas. This has the effect of combining the arena and concourse HVAC units into one system [3]. When smoke or fire conditions prevail, a special control strategy alters the operation of the fans and dampers to allow the removal of smoke in the arena and spectator areas.

The design conditions for sporting and special event facility HVAC systems are based on occupancy load. ASHRAE Standard 62-1999 outside air ventilation rates and arena latent load can end up being a major portion of the total load [7]. The facilities are designed to meet comfort and indoor air quality (IAQ) requirements when thousands of people are in attendance, but this is likely to be the case only 500 to 800 hours a year [3]. In the design of the systems at the Alexander Memorial Coliseum at McDonald's Center, on the Georgia Institute of Technology campus in Atlanta, 750 equivalent full-load hours were estimated [4]. The 1996 Olympic Stadium designers had to take into account the following four primary load conditions: 1) initial use during the 16 day period of the Olympics, 2) the final use as a baseball stadium with a schedule of 81 home games, 3) the daily use of the Braves office facilities, and 4) the off-peak base load [8]. Many functions are relatively small, such as team practices or civic meetings, and require only a fraction of the system design capacity. Multi-purpose arenas face a variety of loading situations, and require flexible AHU control and zoning to successfully minimize operation costs while maintaining satisfactory comfort and safety requirements.

OPTIMIZATION MEASURES

In the process of Continuous Commissioning, the majority of the energy using systems are investigated as a source of possible ECMs. Each facility has its own distinct features, but portions of these systems are common to every building. The primary sources of energy use, and thus the focal points of CC work, are the chillers and cooling distribution system, heating plant and distribution system (along with domestic hot water), and the air handling systems. Additional priorities in large facilities include exhaust fan systems and the facility lighting.

Chilled Water System

While some university arenas have chilled water supplied from a campus facility, special purpose chiller plants abound [4]. Large facilities often have several chillers. There are seven in the case of the Trans World Dome in St. Louis [9]. The chilled water systems for the arena and the office areas are often separated since the office area has a relatively constant load. In systems with multiple units, the chillers can be staged as the building load dictates. This was the intent of the designers of the Olympic Stadium in Atlanta, as it has a 250-ton chiller for the office section and stadium stand-by base loads and a 550-ton chiller for the rest of the game day load [8]. Staging the units reduces pump system requirements and as well as reducing unnecessary cooling energy usage. When considering the chillers and chilled water distribution, a chilled water reset schedule is ideally incorporated during periods of minimal building load. Examination of the distribution loops may suggest the possibility of reducing pumping power. Using variable speed pumps and optimal differential pressure control set points, pump power consumption can be minimized. Constant volume pumping systems with bypass loops can be converted to variable speed pumps, provided chiller minimum flow is be taken into consideration. Additionally, in select systems and climate conditions, a water-side economizer may be beneficial [6].

Hot Water System

Hot water is often produced through heat exchangers by using steam provided from a central plant. In the case of a stand-alone arena, a special purpose boiler may be used. Hot water supply temperature is usually reset based on outside air temperature. This is especially true for constant volume hot water pumping systems, as will be seen in an example later.

Chiller plants can also be used as part of the heating plant, via heat recovery on the condenser. However, an alternate heat source capable of meeting peak load situations is advisable [6]. Chillers, as well as various ice making and refrigeration systems all reject heat. Water source heat pumps have numerous applications in arena facilities [3]. In heating water and steam systems, the principles of staging units, minimizing pumping requirements, and water temperature reset apply as in the chilled water systems. Three two stage heat exchangers were used for the St. Louis Trans World Dome, with the second stage subcooling the steam condensate in an effort to minimize the amount of purchased steam [9].

Domestic Hot Water System

The building domestic hot water system may potentially be a component of the heating water system. With separate domestic hot water systems for the arena space and spaces that are more regularly occupied, there is potential to shut off unused systems when not in use. Again, multiple heat exchanger can be staged. In other systems, the use of heat pumps instead of typical electric water heat should be considered [3,10].

Air Handling Units

The main focal point of building CC work is the air handling systems. Air handling units are a common feature in arena and multi-purpose facilities, and use considerable amounts of heating, cooling, and electrical energy. The AHU control strategies, outside air fraction, air balance, and the condition of mechanical and electrical hardware components must all be examined in detail.

The control strategy is critical. The air handling units and terminal boxes can only perform as well as they are instructed by the EMCS. The AHU may condition the space without fault and be needlessly wasting energy. The priorities and desired system performance criteria should be re-evaluated in light of both full and part load conditions. With large units, such as those that serve the arena floor and spectator seating, small changes to key parameters, such as to the cooling discharge temperature, can have dramatic effects. Control points, such as deck temperatures, static pressure set points, space humidity and CO_2 levels, and economizer operation parameters all have energy saving and wasting potential. Control strategy changes for periods of peak loading can be expected to be minimal. For all other operation, the AHU zones and control strategies should be aggressively tooled for efficiency. Building zones that are predominantly unoccupied should be evaluated for minimal airflow requirements and deck set points and reset schedules. Where CO_2 and humidity level control exists, the need for such control in such circumstances should be reviewed and analyzed. To minimize energy usage, the arena AHUs should be cycled to maintain the space temperature and humidity within certain liberal ranges during the standby periods.

Outside air fraction also comes into consideration. With operation during high occupancy or other times with noxious IAQ issues, such as a monster truck rally, a large outside air fraction is necessary. Economizer cycle operation is common in stadiums and multi-purpose facilities as well. Outside air fraction has dramatic effects on AHU system performance, particularly in extreme design summer and winter situations. Eliminating unnecessary outside air, unless free cooling is available and advantageous, is desirable. This is a priority for operation during periods of low space occupancy. Care must be taken to do this in such a way that IAQ is not compromised. ASHRAE standard 62-1999 calls for a limit of 1,000 ppm for CO_2 concentration [11]. CO_2 sensors are often used to control outside airflow to keep the CO_2 levels at or below IAQ standards [5,9].

Proper air balance will affect building comfort levels and energy usage [12]. When the building has been air balanced recently this should not be much of a factor. This is connected with the outside air fraction issues, but higher than necessary airflow rates will have an adverse affect on operating costs.

Air handling units and air distribution boxes that are failing to operate properly can have dramatically adverse effects, as will be illustrated later. Often, a device may be faulty, or a sensor may simply be out of calibration. Such problems often result in occupancy complaints, but the operations staff is not always able to correctly diagnose the malfunction [13]. This further compounds the problem. Field inspection is a reliable way of verifying proper system operation, but is very time intensive and costly.

Lighting and Exhaust Air Systems

The building lighting and air exhaust systems are also worth mentioning in light of energy management considerations. Lighting is something the operations staff has a good feel for, and may not be an issue. Computerized dimming control, motion sensors, and T8 lamps with electric ballasts may be potential retrofits if they are not already in place. Exhaust fans must be properly evaluated, as their operation can potentially remove large amounts of conditioned air. Building zone pressurization and minimum airflow requirements are affected by exhaust fan operation as well. Ideally, make-up air is provided for kitchen and concessions exhausts [3].

CASE STUDY RESULTS

Various energy conservation measures of the primary systems of large event facilities have been reviewed. From Continuous Commissioning experiences, four examples will now be elaborated on. The following brief case studies demonstrate the need and benefits of CC work.

Water Loop Balance

The first case involves an arena located at a university in central Pennsylvania. The arena has its own chiller plant and receives steam from the university central plant to produce hot water. Prior to the CC work, serious problems existed in the hot water loop. Many hot water control valves were damaged during the first two years of operation. Investigation of the hot water loop revealed that the problem was caused by excessive water pressure in the lines.

The hot water loop has two identical 2-speed hot water pumps in parallel. While one of the pumps is on duty and the other on standby. The pump speed control is based on event type. When there is a large event, the pump is operating at high speed; when there is a small event, the pump is operating at low speed. However, it was found that under high speed operation, there were excessive pressure difference across heating coils throughout the arena, even with all the coils in wide open position. Although hot water temperature is reset based on outside air temperature, the excessive pressure problem still exists during mild weather conditions.

Excessive water pressure not only damages control valves, but also lifts the control valves and results in unnecessary reheat energy consumption. Ultimately this has to be compensated for by additional cooling load. As a temporary measure, one hot water pump is assigned to be operated at low speed only; the other pump is assigned to be operated at high speed only. The manual valve at the discharge and suction sides of the high speed pump were throttled to provide the necessary differential pressure for the arena. It was recommended that a VFD be installed to control the differential pressure of the hot water loop. It was estimated that $5,850 of pump power and thermal energy could be saved each year. Other benefits are: 1) reduction of the maintenance cost associated with damaged control valves as a result of excessive differential pressure; 2) improved comfort; and 3) improved valve control and pump management. Control valves will function better under less loop differential pressure.

Domestic Hot Water System

For the second illustration, a domestic hot water system was investigated while in a limited heating requirement situation in warm fall weather conditions. Heating water was being supplied from a university campus plant, and was the source of domestic hot water through the use of two heat exchangers. An individual heat exchanger layout can be seen on the following page in Figure 2. The building EMCS indicated 300 plus gpm of hot water flow through the building, with a differential temperature of approximately 4°F. In the process of investigating a domestic hot water complaint, the

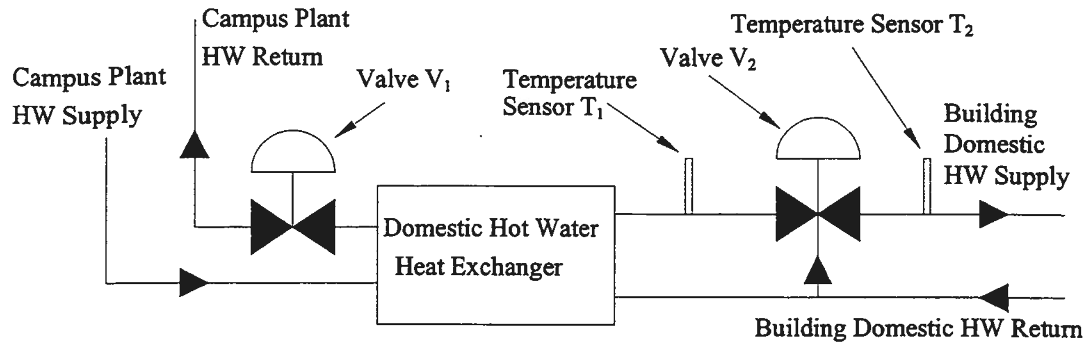

Figure 2. Domestic Hot Water Layout

control program itself was found to be the problem. The control program called for 140°F at temperature control point T_1, and controlled valve V_1 accordingly. 120°F was called for at temperature control point T_2, and was achieved by 3-way control valve V_2 blending water exiting the heat exchanger and recirculation water. However, until recently, the campus hot water supply temperature was only slightly above 140°F at the plant. As a result, valve V_1 was fully opened and approximately 130°F water was being sent back to the campus plant. Upon lowering the 140°F set point at point T_1 to that of the desired domestic hot water temperature, the building hot water flow was nearly halved and the building differential temperature jumped to a reasonable value. This affected the campus hot water loop, and water was made more readily available to buildings further down the pipeline.

Arena Air Handling Unit

In the third case, a large AHU was evaluated during a warm weather time period. The AHU served the arena floor and spectator seating. A system line diagram is shown in Figure 3. The unit had been performing adequately during sporting events and functions. Upon studying the unit's operation under minimal loading, it was found to be continuously cooling the mixed air to 50°F and reheating it to above 70°F. Minimal loading consisted of the stage and facility set-up staff and potentially an athletic team during practice. Only one large arena AHU was used during such times. While the AHU was equipped with CO_2 and humidity control, it was discovered that the face bypass damper was the source of the problem. The linkage was loose and slipping. The control program pressure range was not correct as well, and the damper was not allowed to fully bypass the cooling coil. Correcting the face bypass damper problems and modifying the control program to minimize warm weather arena reheat resulted in immediate energy savings of more than 1.2 MMBtu/h reheat and 1.0 MMBtu/h sensible cooling energy when the unit was in use.

Exhaust System Operation

The fourth example also involved the arena in central Pennsylvania. The operation of its exhaust system created building comfort problem (cold complaints) and resulted in extra

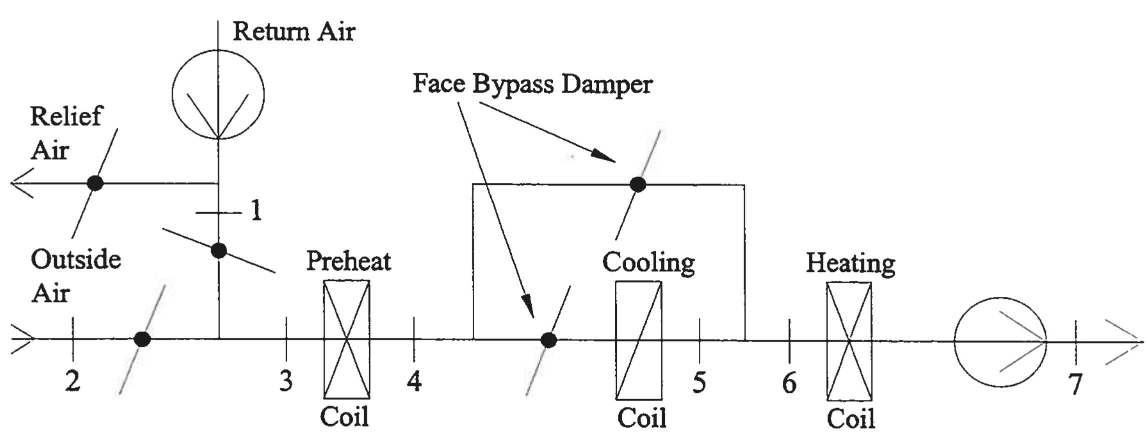

Figure 3. Arena Air Handling Unit Line Diagram

energy consumption.

There are several kitchens located at the concourse level of the arena. Each kitchen is served by one AHU, which also serves part of the concourse space. The operation sequence turns off the AHUs and exhaust fans on the concourse level when there is no event. However, the operator soon discovered that he had to replace half a dozen burned-out refrigerator compressor motors in the kitchens due to lack of ventilation. To cool the kitchens when the AHUs are off, the operator turned on the kitchen exhaust fans and left them on all the time. As a result, the compressor motors stopped burning up. However, cold complaints started to come in from the building occupants during the winter. It was found that the building was under negative pressure with all the kitchen exhaust fans operating all the time. Air infiltration created comfort problems and the AHUs needed to have been operated longer to warm up the space temperature.

To solve this unique problem, it was recommended that the kitchen exhaust system be retrofitted by adding a ductwork and a fan to exhaust the air to the mechanical room (which is open to the arena concourse level) when the kitchen is not in use. This approach is preferred since it captures the heat generated by the refrigerating equipment in the kitchen. Based on total exhaust airflow of 17,500 cfm, total heating energy savings amount to approximately $16,000/year if this waste heat is utilized. An alternative approach is to use the following operation sequence: instead of leaving the exhaust fans on all the time, turn on the concourse level AHUs when the ambient temperature is low (for example, below 50°F). By operating these AHUs with 100% return air, the kitchens will be ventilated. Although this operation leads to some fan power consumption penalties, it is more than offset by the benefits of being able to capture the heat produced at the kitchens, as well as reduce the whole building AHUs run time. When the ambient temperature warms up to over 50°F, the exhaust fans are kept on in order to remove the heat rejected by the refrigerators.

CONCLUSIONS

This paper presents an overview of the design and operation of sporting and special event facility. Potential optimization measures are given and illustrated through some case study examples. From the case study examples, the need for Continuous Commissioning and the benefits can be clearly seen. Operating costs for any facility are considerable, and even small percentage energy savings are significant. Considering arena energy systems in light of the Continuous Commissioning points presented will aid in energy management in any facility, and be of benefit in the planning of any new complex.

REFERENCES

1. Claridge, D. E., J. Haberl, M. Liu, J. Houcek, A. Athar, 1994. "Can You Achieve 150% of Predicted Retrofit Savings: Is It Time for Recommissioning?" ACEEE 1994 Summer Study on Energy Efficiency In Buildings Buildings Proceedings: Commissioning, Operation and Maintenance, Vol. 5, American Council for an Energy Efficient Economy, Washington, D.C., p.73-87.

2. Liu, M., J. Houcek, A. Athar, A. Reddy, D. Claridge, 1994. "Identifying and Implementing Improved Operation and Maintenance Measures in Texas LoanSTAR Buildings." ACEEE 1994 Summer Study on Energy Efficiency In Buildings Buildings Proceedings: Commissioning, Operation and Maintenance, Vol. 5, American Council for an Energy Efficient Economy, Washington, D.C., p.153-165.

3. Monteyne, R., 1995. "HVAC Design Solutions for Multi-Purpose Arenas." ASHRAE Journal, Vol. 37, No. 11, p. 22-32.

4. Dustin, R. 1997. "Modernizing Sports Facilities." ASHRAE Journal, Vol. 38, No. 9, p. 32-38.

5. England, R. J., A. J. Thomson, and B. J. Ford. 1991. "Practical Application of a Carbon Dioxide Monitoring System to Control Outdoor Air in an Athletic Fieldhouse." ASHRAE Transactions, NY-91-7-3, Vol. 97, Part 2, p.620-624.

6. Louria, D., 1996. "Solving the Energy Dilemma at Seven Bridges Ice Arena." ASHRAE Journal, Vol. 38, No. 8, p. 67-70.

7. ASHRAE 1999. "Handbook of HVAC Applications", American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

8. Anonymous, 1996. "Stadium Designed for 'Second Use.'" ASHRAE Journal, Vol. 38, No. 6, p. 24-27.

9. Towell, R. L., 1998. "HVAC for Domed Stadium." ASHRAE Journal, Vol. 40, No. 7, p. 47-50.

10. ASHRAE 1996. "Handbook of HVAC Systems and Equipment", American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

11. ASHRAE 1999. "ANSI/ASHRAE Standard 62-1999, Ventilation for Acceptable Indoor Air Quality." American Society of Heating Refrigerating, and Air-Conditioning Engineers.

12. Liu, M., Y. Zhu, B. Y. Park, D. E. Claridge, and D. K. Feary. 1999. "Airflow Reduction to Improve Building Comfort and Reduce Building Energy Consumption-A Case Study." ASHRAE Transactions, No. 4271, Vol. 105, Part 1, p. 384-390.

13. Trueman, C. S., 1989. "Commissioning: An Owner's Approach for Effective Operations." ASHRAE Transactions, Vol. 95, p. 895-899.