rightsizing HVAC systems

to reduce capital costs and save energy

By James Sebesta, P.E.

Nearly every institution is faced with the situation of having to reduce the cost of a construction project from time to time through a process generally referred to as "value engineering." Just the mention of those words, however, gives rise to all types of connotations, thoughts, and memories (usually negative) for those in the facilities departments of most educational institutions. The University of Minnesota has taken a more proactive approach and has moved to rightsize its HVAC systems as part of a value engineering and cost containment process for some of its building projects.

Northrop Auditorium, one of the original campus icons located at the head of the central mall of the University of Minnesota, is scheduled for a major interior renovation to return the facility to its rightful place on a list of world-class performance halls on university campuses. This project follows on the heels of an external preservation project completed a few years earlier. However, cost increases were placing the project in jeopardy of cancellation. Searching for options to reduce costs without reducing program, the University of Minnesota, through the construction manager, retained a consulting firm to provide an analysis of and recommend modifications to the mechanical systems in an effort to reduce costs while preserving the program and performance of the systems serving the building.

Most recently, during the schematic design phase pricing exercise for the $61 million Phase 2 renovation of Northrop Auditorium, rightsizing discussions and exercises were undertaken with the design team and construction manager to understand the capital cost premium for HVAC systems being designed just to accommodate the occasional maximum occupancy moments during peak weather occurrences.

It is a well-known fact amongst facility staff that HVAC systems operate most efficiently when running in a steady-state condition and close to system design capacity. HVAC systems for typical classroom, administration and assembly buildings, however, are almost never operating near design capacity due to the variability of occupancy, weather conditions and internal load and the low probability that peak conditions for all the variables will occur coincidently.

Before we discuss the details of the exercise at the University of Minnesota, let's first examine how we got to the situation of conservatively sizing HVAC systems. Design standards and the contingencies employed by many HVAC design engineers and their firms are the result of experiences or the lack thereof. Engineering in itself is a science predicated on the laws of physics. Calculations are completed based on known facts about a facility at peak conditions for minimum and maximum temperature conditions, occupancy, internal equipment loads, and other known factors. We can easily calculate the conditions at each end of the spectrum, i.e., fully loaded occupancy and equipment use at extreme weather conditions and unoccupied conditions. Based on these facts, we can properly size system capacity at the individual room level for these maximum load conditions.

The next steps, however, begin with contingencies based on experiences. What safety factor should be employed due to: 1) faulty construction techniques, including poor insulation, building air leakage, and duct leakage, 2) temperature degradation in air or water transport systems, 3) using outdoor or indoor design conditions that exceed mean coincidental conditions defined in the various standards and energy codes, 4) capacity degradation due to maintenance procedures during the life of the system and building, and 5) changes in space occupancy and use over time.

Engineering safety factors are usually due to experiences (owner and occupant comments on performance issues from past system) that have become aggregated over time. Thus we have the basic building blocks for a system that is sized to handle any and all peak conditions in the future, but one that will run at a significantly reduced capacity most of the time as a result of occupancy that is typically less than its peak design. But

In a majority of the buildings designed and constructed in the recent past, where system capacity was not highly evaluated, I would challenge facility staff to identify more than a small minority of buildings that ever operated at design capacity for any appreciable time.

Application of these “safety” factors cannot always be identified or attributed to any one item. However, I would venture to say that it is a culmination of many factors in the design and construction industry. Some reasons include inconsistent quality of construction; lack of communication during the design phase between engineer and owner to discuss the impact of these factors and associated cost/benefit; continual pressure on fees, both from the contractor and the architect/engineer perspective; and a misunderstanding of the criteria used for system design by the engineer due to their fear of impact to reputation or litigation if the system does not maintain conditions in the occupied spaces as expected or assumed by the owner anytime during the life of the building.

For Northrop Auditorium’s renovation, rightsizing began with the review of HVAC system sizing and zones served by various independent HVAC air handling systems. The first step was to determine if any system could be combined to reduce the total number of HVAC units thus reducing the costs associated with installing a larger number of air-handling units, which also freed up more building square footage. The initial indications were that the HVAC units serving the classrooms and lecture halls could be combined with the unit serving the lobby, main foyer, corridors, and common and open dining areas. Based on initial assessments, these two units would generally be running at the same time.

Once units were combined, the next step was to reduce system capacity by recognizing the diversity of occupancy loads and how the associated equipment capacity for heating and cooling the spaces were impacted primarily by people load, outdoor ventilation load (a direct relationship to the people loads), and internal lighting and equipment loads. Consider the example of a typical office building and the resulting HVAC system load variability driven by occupant diversity. This example assumes 10,000 square feet of office, with standard occupant load (work station and offices of 50 people, 1 large conference/lunch room to handle 45 people, and 3

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small conference rooms each set up to handle 15 people).

With a reasonable review of the space use and the type and variability of the occupant load, one could rationalize a peak building occupancy of 75 people, assuming all 50 people were in the office and there were an additional 25 people in the building for meetings in the conference room. Now, if the project employs occupancy sensors and day lighting controls and automatic sleep mode for computers and work station task lighting, it is easy to see that rightsizing the system will not lead to discomfort of the occupants in the building.

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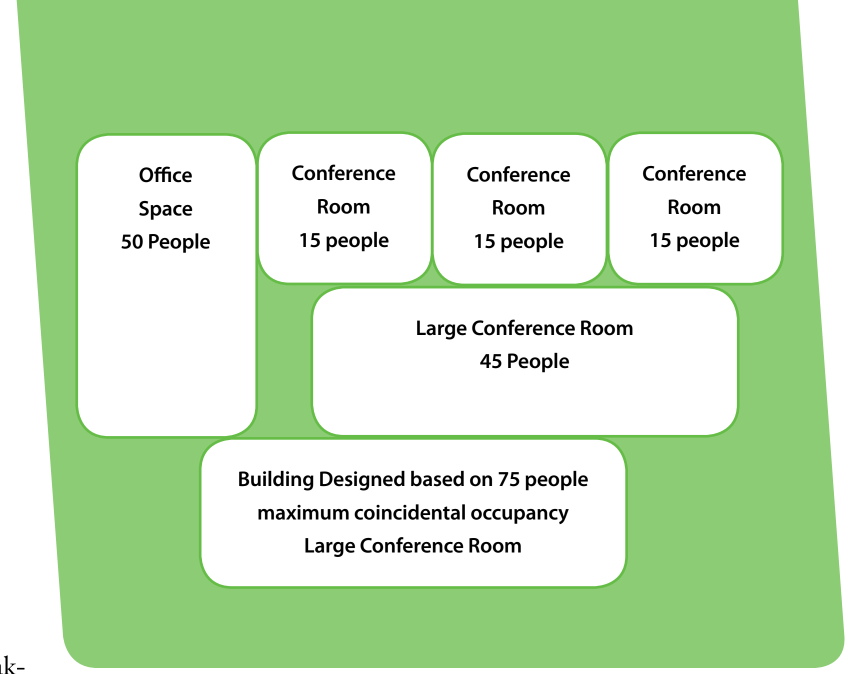
Coming back to the Northrop Auditorium project, the occupancy of these spaces is such that the lobby, hall, and commons areas will generally be transient traffic at the high occupancy number (people moving into and out of the lecture areas or audience auditorium). The load calculations can be based on short-term and periodic occupancy. It is also assumed in this exercise that the main 2,800-seat auditorium is not fully occupied when the academic, lecture, and office areas are fully occupied, given an analysis of how the space is used. The following Process Flow Graphic depicts a simplified analysis and decision tree for three of the five HVAC air-handling units.

The preliminary results of the adjustments for these three initial air handling units show an elimination of one air handling unit, a reduction of nearly 30,000 CFM in total system capacity and a reduced load on heating and cooling system capacity associated with the elimination of 3,100 coincidental occupants at 5 CFM of outdoor air per person. Thus the university realized cost savings for the project through value engineering that has not compromised any of the quality of the systems.

Similar exercises were undertaken for the HVAC systems serving the performance portions of the building (stage, orchestra pit, warm-up area, rear stage, and lecture areas) and the back of house area with its storage, construction, practice, staging, conference, and general support areas.

WHY CAN THIS HAPPEN?

Any project can be approached in this manner. There are tools and processes



available that were not previously as readily accessible or as well perfected as they are today.

The first of these is the use of commissioning for new and renovated buildings. Part of the standard process of commissioning a project is the development and communication of a clear design intent document (DID). A good DID will define:

- an understanding of how the building is going to be used, occupied, operated, and maintained
- the design parameters used for system sizing, including indoor and outdoor design conditions
- equipment loads, occupancy schedules, and lighting systems used for the spaces
- assumptions used for building air leakage rates, duct leakage rates, and air and water temperature degradation and equipment performance are verifiable during a high-quality commissioning process.

These factors can then be used during the commissioning process to confirm that the systems operate and perform in accordance with the owners expectations as defined in the DID.

The second tool is quality building design and modeling software. With these tools, the owner and engineer can begin to understand the ramifications of any decisions or assumptions made for occupancy schedules, equipment and lighting system loads, and external temperature and humidity conditions. With the knowledge that an impact of one or more factors may increase the temperature in the space over two hours by 4 degrees, and that the occupancy schedule is expected to be 45-minute lectures except for five times per year during finals, the Owner can make informed decisions to guide the engineer's design.

Finally, high-quality maintenance and monitoring processes are in place to assure that significant degradation of system performance can be repaired before it impacts occupant comfort and energy consumption.

All of these tools lead to a better project and a more informed owner, contractor, architect, and engineer team, thus minimizing the issues that can lead to litigation or dissatisfaction from building operation and performance.

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CONCLUSION

By taking a more active role in the design of the building HVAC systems, the University of Minnesota is not only able to reduce the construction costs for the Northrop Auditorium Renovation, but future operating costs primarily associated with energy consumption for the building will also be reduced. To achieve this goal however, the university had to become comfortable understanding the impact on operations of the HVAC systems based on the decisions and directions given to the designers. This includes operating conditions and comfort maintenance based on weather and occupancy trends for the building.

Past practices are not the best practices when it comes to designing and operating efficient building HVAC systems. Rightsizing HVAC systems not only uses current resources efficiently, it also assures that use of future resources, money, and energy are optimized to the benefit of the university and its future stakeholders.

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