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Commissioning Lessons from Study of the Advanced Systems at the CMU Intelligent Workplace

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Executive Summary

The individual commissioning lessons learned from this study of the advanced system in the Intelligent Workplace may be summarized and generalized as follows.

1. Advanced systems are likely to have very important design characteristics that must be thoroughly considered during the design process to achieve expected performance, illustrated by the need to consider the characteristics of mullion design, and the importance of contact resistance to radiant panel performance.
2. Advanced systems may require unconventional control techniques to achieve optimum performance, and this may not be obvious to the design engineer. This is illustrated by the imperative to use operative temperature as the control variable instead of space air temperature for mullion type radiant heaters.
3. Proper sizing of systems is critical for optimum energy performance of many advanced systems, just as it is for conventional systems. This may be even more important with advanced systems where limited size options may exist. This is illustrated by the oversized desiccant system in the building studied.
4. Expected energy performance of advanced systems can depend critically on proper commissioning of the entire system, as illustrated by the higher than expected infiltration in the case study building resulting in the advanced desiccant system having higher energy consumption than a conventional single duct VAV system.

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Introduction

A detailed study has been conducted of the performance of several innovative aspects of the Intelligent Workplace (IW) at Carnegie Mellon University, a low energy consumption building that uses radiant heating, cooling and a desiccant ventilation unit. The following aspects have been studied in detail: the heat transfer process of radiant mullions and overhead radiant panels, the impact of the radiator position on heating load and thermal comfort, the influence of infiltration on indoor humidity in a radiantly cooled office with a solid desiccant ventilation unit, and an energy consumption comparison of the sensible heating and cooling systems with a single duct VAV system. This report summarizes the conclusions and observations relevant to commissioning of such buildings.

Simulation and Verification Study of the Radiant Mullions

The IW radiant mullion system is one type of façade heating and cooling system. No detailed study of such systems was found in the available literature. The heat transfer process of window mullion radiators was studied and a group of models were developed to simulate the performance of radiant mullions. The simulation results were compared with ten days of measured data. The comparison found that the heat transfer models predicted the measured temperatures with root mean square errors (RMSE) of the hot water return temperature, mullion surface temperature, and window surface temperature of 0.90°F, 0.98°F and 1.15°F, respectively:

The performance study of radiant mullions showed that hot water and chilled water supply temperatures are the primary factors affecting the heating or cooling capacity of radiant mullions and the mullion surface temperature. The window surface temperature distribution is affected by the mullion surface temperature and the inside and outside air temperatures. The temperature gradient on the glazing surface within one foot from the mullions is much higher than in the central part of the window. The temperatures in the central 2 feet of a 4-foot window show almost no influence from the mullion surface temperature.

The conductive thermal resistance of the mullion double tubes and gap filling plays a decisive role in controlling the mullion and window frame temperatures. An increased mullion tube conductive resistance results in a lower surface temperature for heating and a higher surface temperature for cooling. The higher surface temperature for cooling may be intended to lower the risk of moisture condensation on the surface of the mullion in the cooling condition. However, the enhanced thermal resistance decreases the heating and cooling capacity of the mullion. If the mullions are only used for heating, a single tube structure would provide better performance.

From the design perspective, the window width or spacing between the mullions has little impact on the heating capacity or mullion surface temperature. However, the space between the mullions will somewhat affect the window inner surface temperature distribution and average window temperature.

This portion of the study provided little of direct relevance to commissioning, except the observation that a mullion used only for heating should use a single tube designs – information that would be useful in design phase commissioning of a building that will use such systems.

Simulation Study of the Overhead Radiant Panels

The heat transfer principles of the overhead radiant panels were studied and a heat transfer model set up. The model can be solved for the supply water outlet temperature, average panel surface temperature and overall panel surface heat transfer coefficient. The study found that the heating and cooling capacity of the overhead panel without top insulation is a semi-linear function of the supply water temperature when the flow rate is fixed.

The cooling capacity of the overhead radiant panel is around 45 Btu/(hr-°F) at a chilled water supply temperature of 55ºF; it is greatly affected by the room air temperature and slightly affected by the water flow rate. The heating capacity of the overhead radiant panel is around 144 Btu/(hr-°F) at the hot water supply temperature of 120°F. Room air temperature and supply water flow rate affect the heating input of the overhead radiant panels. The heating capacity increases by 8.5% when the room air temperature drops from 72ºF to 68ºF, and it decreases 14.2% if the hot water flow rate is reduced to half of the design flow rate.

The thermal contact resistance between the water tubes and the aluminum radiant panels has a significant impact on the thermal performance of the overhead radiant panels. When the thermal contact resistance increases to 0.2 Btu/(hr-°F), the cooling capacity drops 18.6% and the heating capacity drops 20.6%. The thermal contact resistance should be reduced to be as small as possible in the design processes.

This part of the study indicates that contact resistance between the water supply tubes and aluminum radiant panels used in this building has a major impact on panel performance – a factor that should be carefully considered by the commissioning authority in the design process.

The Impact of the Radiator Position on Heating Load and Thermal Comfort

The position of the radiators in a radiantly heated office has been shown to impact the heating load and the thermal comfort distribution inside the room. When radiators are close to the window, the increase of window surface temperature is higher than when the radiator is located in the center of the ceiling. The energy savings relative to the convective air system depend on the outside air supply rate. When the outside air supply rate and the rate of infiltration increase, the energy savings of the radiant system also increase.

The control device used also affects the energy consumption of a radiant heating system. If the dry bulb temperature thermostat is used instead of an operative temperature thermostat in a radiantly heated space and the air temperature is set at the same point as that which is used for air heating, radiant heating will increase the heating load as much as 11.5% higher compared to the air heating for the cases studied.

On the basis of thermal comfort, radiators located close to the window can reduce down draft, prevent cold penetration inside a room and make the operative temperature distribution much more uniform than when the radiator is located in the center of the ceiling.

This portion of the study found that it is imperative to use operative temperature as the control variable instead of space air temperature or mullion type radiant heaters will significantly increase the heating load in a space. This is an important consideration for both design commissioning and for the operational commissioning of such a system.

Indoor Humidity Analysis and the Desiccant Ventilation Units

The indoor humidity study found that the active desiccant ventilation system dries a space deeply and continuously, while a passive desiccant ventilation system dries a space more energy efficiently. The moisture removal capacity of a passive desiccant system depends on the dryness of the exhaust air. When a passive ventilation system is the only source of dehumidification, the system cannot remove moisture without post-desiccant cooling.

High infiltration is one of the main causes of condensation in a radiantly cooled space during summer. Radiant panels cannot work without condensation in a leaky space, even if the supply air is conditioned to 52^{o}F, 0.008lb/lb. Pressurizing the space with ventilation air is one possible solution available for avoiding water condensation on the surface of radiant cooling panels in a leaky building. The infiltration and ventilation rate has a significant impact on energy consumption. The primary energy consumption was simulated to increase by 36% when the infiltration rate increases from 0.0 to 0.45 air changes per hour in the space studied as might be expected; at the same infiltration condition of 0.45 ACH, the primary energy consumption increases by 42% when the ventilation rate increases from 650 CFM to 1600 CFM (as is the case in the IW).

The commissioning lesson from this study is that, as is often the case, proper sizing of systems is critical for optimum energy performance.

Comparison of IW Radiant System with a Single Duct VAV System

The IW used radiant heating and cooling with a passive desiccant ventilation unit before the winter of 2005. The passive desiccant ventilation system was replaced by an active desiccant ventilation system during the winter of 2005. A group of fan coil units are planned for installation in the southern zone to offer additional cooling in the future. The sensible heating and cooling system of mullions, radiant panels, “cool wave” chilled beams (with a slowly oscillating fan) and fan coils in the IW has been simulated. The daily and monthly thermal, electricity and primary energy consumption of the IW sensible heating and cooling system was compared with a single duct VAV air heating and cooling system. The results showed that the current system with an integrated active desiccant ventilation unit consumes about 28.5% more thermal energy, 2.8% less electricity and 5.6% more primary energy than a single duct VAV air heating and cooling system. The current system with a presumed integrated passive desiccant ventilation unit consumes 21.0% less thermal energy, 2.3% less electricity and about 11.4% less primary energy than a single duct VAV system. On the basis of thermal comfort, the current integrated active desiccant ventilation system can easily control the relative indoor humidity ratio below 50% (0.009lb/lb, 73°F) in the summer, while the integrated passive desiccant system and the air heating and cooling system cannot control the indoor humidity ratio very well. The relative indoor humidity ratio varies between 45% and 70% (0.0012lb/lb, 73°F) in the summer when using these two types of systems.

By assuming that the infiltration is close to zero and the ventilation is a value of 650CFM (a value that meets ASHRAE Standard 62) for the three systems, it was found that the primary energy consumption of all three systems would be substantially reduced as expected: 17.3%, 34.0%, and 29.8% for the air, integrated active, and passive systems, respectively. The primary energy consumption of the integrated passive desiccant system would be 24.8% less than the single duct VAV air system. The primary energy consumption of the integrated active desiccant system would be 15.7% less than the single duct VAV air system, and provides much better indoor humidity control.

The critically important commissioning lesson from this study is that the superior energy performance expected from the desiccant systems is critically dependent upon a low infiltration rate, and hence upon careful commissioning of the system after installation. Otherwise, the additional expense of the advanced system may result in no savings, or in the system as currently operated, uses more energy than a conventional system.

Summary of Commissioning Lessons from the Advanced Systems at the Intelligent Workplace

The individual commissioning lessons learned from this study of the advanced system in the Intelligent Workplace may be summarized and generalized as follows.

5. Advanced systems are likely to have very important design characteristics that must be thoroughly considered during the design process to achieve expected performance, illustrated by the need to consider the characteristics of mullion design, and the importance of contact resistance to radiant panel performance.
6. Advanced systems may require unconventional control techniques to achieve optimum performance, and this may not be obvious to the design engineer. This is illustrated by the imperative to use operative temperature as the control variable instead of space air temperature for mullion type radiant heaters.
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