Can we achieve energy efficiency and good IAQ in buildings?

Lal Jayamaha*

Energy Centre, PREMAS International Limited, Singapore

ABSTRACT

Air-conditioning and ventilation systems, which help to maintain the indoor environment of buildings, account for more than half of the energy consumed in them. While it is necessary to improve the energy efficiency of buildings due to economic and environmental reasons, it is important to do so without compromising their indoor environment. Various optimizing strategies for air-conditioning and ventilation systems that help to improve energy efficiency while enhancing the quality of the indoor environment of buildings are described in this paper.

INDEX TERMS

Energy efficiency; Air-conditioning; Ventilation; HVAC systems; Indoor air quality

INTRODUCTION

Due to environmental concerns and the need for reducing operating costs, building owners and operators around the world are increasingly looking at ways to improve the energy efficiency of buildings. Meanwhile, occupants of buildings are also demanding better indoor environments to ensure that the buildings they work and live in are comfortable and healthy. Therefore, it is necessary to achieve both energy efficiency and good indoor air quality (IAQ) in buildings without compromising each other.

Energy in the form of electricity is used in buildings for operating systems such as air-conditioning, mechanical ventilation, lighting and vertical transportation and is essential for ensuring the safety and comfort of building occupants. Air-conditioning and mechanical ventilation (ACMV) systems account for more than half the electricity consumed by commercial buildings in Singapore.

The electricity consumption of each main user as a percentage of the total building consumption (including landlord and tenant consumption) for a typical commercial building is shown in Figure 1. As the figure shows, ACMV systems consume the most, accounting for about 55%, while lighting consumes about 20% of the total consumption. Miscellaneous consumption, which includes lifts, escalators, office equipment and appliances, accounts for the balance 25%.

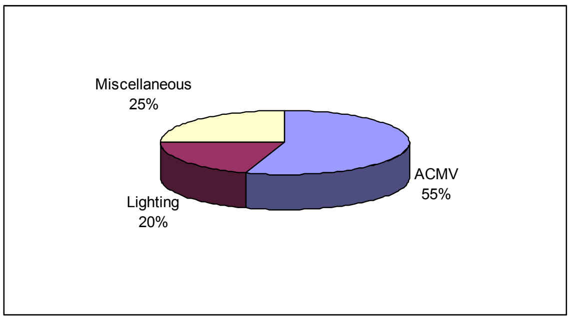

Figure 1 End-user breakdown.

Normally, air-conditioning for commercial buildings is provided by central air-conditioning systems that consist of a central chiller plant with distribution pumps and cooling towers. Chilled water from a central plant is distributed to air handling systems in the building that

* E-mail: sharmilal@premas.com

help to provide the necessary space, cooling and ventilation. Building ACMV systems can be generally categorized into 'water-side' systems and 'air-side' systems. Water-side systems include chillers, pumps and cooling towers, while air-side systems include air handling and ventilation systems.

Figure 2 shows the electricity consumption of water- and air-side systems as a percentage of the total electricity consumption of ACMV systems in buildings. As the figure shows, water-side systems consume about 75%, while air-side systems consume the balance 25%. Although air-side systems consume only 25% of the total ACMV electrical consumption in buildings, they have the biggest impact on the IAQ and the indoor environment of buildings. Meanwhile, water-side systems, which account for 75% of the total ACMV pie and about 40% of the total building electricity consumption, have a far lower effect on the building environment compared with air-side systems.

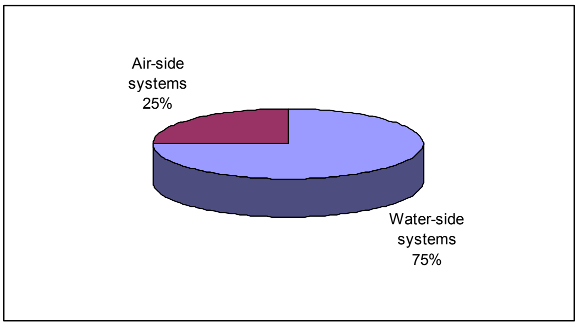

Figure 2 Water- and air-side consumption.

Therefore, it is clear that the maximum energy savings can be derived from water-side systems without affecting the indoor environment of buildings. Conversely, for air-side systems, while the potential for achieving energy savings is less, great care needs to be taken to ensure that energy savings are not achieved while compromising the quality of the indoor environment of buildings. Nevertheless, it is important that both water- and air-side systems be considered collectively in order to maximize the energy efficiency of buildings.

The following sections of the paper describe design and operating strategies for both water- and air-side systems to achieve energy efficiency while improving the IAQ of buildings.

WATER-SIDE SYSTEMS

As described earlier, water-side systems are the biggest energy consumers in buildings. Various design and operating strategies that can be used to improve the energy efficiency of these systems to maximize energy savings for buildings are listed below.

Chillers

Efficiency versus cost

Chillers are usually the single biggest energy consumers in commercial buildings and therefore their efficiency has a significant effect on the overall energy performance of buildings.

The efficiencies of new chillers have improved over the last 10 years and chillers having efficiencies of 0.5–0.55 kW/RT are now commonly available. Although high efficiency chillers have a higher first cost, they have a much lower 'life cycle cost' and therefore should be considered for new installations or chiller replacement projects.

Sizing and configuration

The operating efficiency of chillers depends on their loading. Generally, chiller efficiency is best when operating in the range 70–100% of the capacity, while the optimum efficiency is obtained at 80% loading (some chillers operate best at 100%).

Chillers are usually oversized for new building installations due to the unavailability of accurate load estimation tools leading to high safety factors in the design. This oversizing repeats even when the systems are retrofitted since replacement of chillers is often done on a one-to-one basis. Further, chillers are normally sized to meet the peak load without considering the load profile. Since the cooling loads of buildings vary with time, this can result in chillers operating at part-load for long periods of the day, wasting much energy.

Therefore, sizing of chillers for new buildings should be done using more accurate load estimation tools, while the measured cooling load profile should be used when retrofitting existing buildings. Chillers should be sized to match the cooling load profile so that various combinations of chillers can be operated during the day to match the building cooling requirements. This would ensure that the chillers are able to operate within their best efficiency range at all times.

Reset of chilled water temperature

The operating efficiencies of chillers improve when the chilled water supply temperature is increased as the chiller compressor has to work over a lower pressure differential. In general, it is estimated that improvement in chiller efficiency of 2–4% can be achieved by increasing the chilled water temperature by 1°C.

The chilled water temperature can be normally reset upwards based on the cooling load or outdoor temperature to improve chiller efficiency. Latent heat removal by cooling coils depends on the chilled water supply temperature, and therefore raising the chilled water supply temperature could lead to a higher relative humidity in the conditioned spaces. Therefore, care should be taken to ensure that this strategy does not compromise the quality of the building environment.

Chilled Water and Condenser Water Pumps

Pump sizing

Chilled water and condenser water pumps are sized to provide the design flow requirements while overcoming the various resistances in the system. Since the resistances in some parts of the system are usually not known during the design stage, they are estimated based on available data. Due to the uncertainty of the estimated values, a safety factor is added to the design. This very often results in oversizing of pumps, leading to overpumping or use of throttling valves to reduce the flow to obtain design conditions.

For chilled water, overpumping also results in an increase in the chilled water supply temperature, resulting in less dehumidification at the terminal units. In such cases, the design flow rate can be achieved by trimming the impellers or reducing the speed of the pumps (using variable speed drives). However, reducing the impeller diameter can result in a bigger drop in pump efficiency when compared with the use of variable speed drives (VSDs) for reduction of speed.

Variable flow systems

In variable chilled water flow systems with terminal units having two-way modulating valves, a reduction in cooling load causes the modulating valves to close, resulting in reduced chilled water flow through the respective cooling coils. In systems using constant speed pumps, this causes the pump operating point to move along the pump performance curve by increasing the system pressure. However, if the pumps are equipped with VSDs, the pump speed can be reduced at part-load to provide the lower flow required, leading to reduced energy consumption by the pumps.

Cooling Towers

If cooling tower fans are fitted with VSDs, the speed of the fans can be regulated to control the cooling tower capacity to match system requirements. This method of cooling tower capacity control is better than the conventional method of fan cycling in which fans are switched ON/OFF to control condenser water temperature. This usually results in big swings in condenser water temperature and also causes premature wear and tear on the motor drives. Use of VSDs for control of fan speed on the other hand not only maximizes energy savings, it also results in better control of temperature, reduction in wear and tear of the drives due to the lower fan speed and less drift losses due to lower air velocity.

AIR-SIDE SYSTEMS

Although air-side systems in buildings consume less energy than water-side systems, their performance have a far greater impact on the indoor environment of buildings. Various design and operating strategies for air-side systems that can help to improve energy efficiency of buildings while maintaining or even improving the IAQ of buildings are listed below.

Low Face Velocity Coils

Generally, air handling units (AHUs) are designed for coil face velocities of 2–2.5 m/s. Although this results in smaller sized AHUs that are cheaper and occupy less space, the excessive air velocity leads to high pressure losses across the cooling coil and filters. As a result, the AHU fans consume more energy to deliver the same amount of air flow. Not only do AHUs that have low face velocity coils consume less electrical energy, they are also more efficient at dehumidification. Even though low face velocity AHUs have a higher first cost, they have a lower life cycle cost and therefore should be considered in place of conventional ones.

Stacked AHUs

In conventional air-conditioning systems, outdoor air provided for ventilation is mixed with the return air before passing through the cooling coils of AHUs. The outdoor air (which forms a small percentage of the total supply air) has a higher enthalpy; when mixed with a large quantity of return air with a lower enthalpy, it reduces the enthalpy of the mixture of air and therefore the potential for moisture removal.

This shortcoming can be overcome by using two separate coils to treat the outdoor air and return air before mixing. In such a system, the coil for treating the outdoor air is designed for carrying out most of the dehumidification. Since the quantity of air for dehumidification is small and the enthalpy is higher, low face velocity coils can be used to provide higher moisture removal at reduced energy cost. The return air cooling coils can have fewer rows and can be sized for providing mainly sensible cooling, leading to lower pressure losses.

Runaround Coils

For areas that require low space relative humidity, usually the supply air is ‘overcooled’ by the AHU coil to remove sufficient moisture and then electric duct heaters are used to reheat the supply air before releasing it to the occupied spaces. This strategy not only wastes energy but also increases the cooling load on the chiller plant.

Reheat for humidity control can be avoided by using runaround coils where two extra coils sandwich the main cooling coil of the AHU. Water is circulated through the two coils using a small pump, which enables transferring of heat from the incoming air (precooling) to the leaving air. Heat pipe systems can also be used to achieve the same effect. Research (Berbari, 1998) has shown that runaround coils can achieve substantial energy savings (about 20% of cooling coils total annual cooling energy) for hot and humid climates.

Variable Air Volume Systems

In constant air volume systems, the AHU fan is sized for the maximum air volume required and the cooling capacity of the AHU is controlled by varying the supply air temperature. Such systems not only waste energy by supplying a constant volume of air irrespective of the load but also lead to high space relative humidity at low loads. To avoid this, variable air volume systems could be used to regulate the quantity of supply air to match cooling load requirements. VSDs can be used to vary air flow by modulating fan speed to maintain a duct static pressure set-point, which will result in significant savings during part-load operations.

An optimizing algorithm (Moult and Tran, 1995) can also be used to further improve this strategy by continuously resetting the static pressure set-point to achieve further savings estimated to be about 20%.

Displacement Ventilation Systems

The concept of displacement ventilation uses the natural buoyancy of warm air to provide improved ventilation and comfort. In displacement ventilation systems, supply air is introduced to the space at or near the floor level, at a low velocity and at a temperature slightly below the required room temperature. The cooler supply air 'displaces' the warmer room air, creating a zone of fresh cool air at the occupied level. Heat and contaminants produced by activities in the space rise to the ceiling level, where they are exhausted from the space.

Displacement ventilation systems are typically more energy efficient because they are designed to provide space comfort only for the occupied zone and they supply air at a higher temperature, leading to better cooling system efficiency. They also provide better ventilation efficiency and thus improved IAQ.

Space Temperature Reset

The temperature set-point of air-conditioned spaces can be varied based on the outdoor temperature or mean radiant temperature. For example, during periods of rain, when the outdoor temperature and mean radiant temperature are lower, occupants in air-conditioned spaces often feel cold if the normal space temperature set-point is maintained. Therefore, resetting the space set-point based on outdoor weather conditions not only helps to reduce energy consumption by the cooling system but also helps to improve comfort conditions.

Occupancy-based Ventilation Control

Outdoor air is required for ventilation and to ensure sufficient building pressurization to prevent infiltration. To maintain good building IAQ, ASHRAE Standard 62 is generally used as a guideline for determining the quantity of ventilation air required per occupant. Building occupancy usually varies during different periods of the day and hence it is not necessary to provide the quantity of fresh air required to satisfy the expected maximum occupancy of the space at all times.

A simple solution is to use carbon dioxide (CO_2) sensors to monitor the CO_2 level in the occupied spaces or the return air at the AHUs and use it as an indicator of occupancy to vary the fresh air flow. Since outdoor air is normally hot and humid compared with the treated indoor air, regulating the fresh intake can lead to a significant reduction in cooling load and therefore energy savings.

Energy Recovery Systems

In air-conditioned buildings, a part of the indoor air is exhausted to maintain the required ventilation rate and pressure balance in the building. The exhaust air is normally colder and has a lower enthalpy than the fresh outdoor air that is taken in for ventilation. Therefore, energy recovery systems such as those using heat pipe systems and heat recovery wheels can be used to pre-cool the fresh air using exhaust air. Buildings which have common exhaust systems and central fresh air intakes like office towers are good candidates for installing such energy recovery systems.

Demand-based Mechanical Ventilation Control

Mechanical ventilation systems consisting of supply and exhaust fans are widely used for providing ventilation for non-air-conditioned building spaces such as basement car parks. These systems are normally designed to provide the ventilation rates required under extreme or worst case conditions. However, ventilation rates required under normal operating conditions are usually much less and it is possible to control the operation of the fans to match the actual ventilation requirements.

For car parks, carbon monoxide (CO) and temperature sensors can be used to monitor the quality of air and used to control the operation of supply and exhaust fans.

CONCLUSIONS

The main energy consumers in commercial buildings are the ACMV systems, which account for more than half the total consumption. Water-side systems, which account for about 75% of this ACMV consumption, are able to provide maximum energy savings without any significant impact on the indoor environment. Likewise, air-side systems, which account for the balance 25%, also provide opportunities for achieving energy savings while at the same time helping to maintain or improve the indoor environment of buildings. Therefore, it is possible to achieve both energy efficiency and good IAQ in buildings.

REFERENCES

Berbari, G.J. (1998). Fresh air treatment in hot and humid climates. *ASHRAE Journal* October, 64–70.

Moult, R. and Tran, J. (1995). Getting an additional 20% energy savings from a VAV system. *ASHRAE Conference—Built Environment Trends and Challenges*, Singapore, pp 25–32.