SPACE CONDITIONING IN COMMERCIAL BUILDINGS

Overview

As in residential buildings the purpose of mechanical conditioning and ventilation is to maintain air quality and thermal comfort in buildings, with the defining difference generally being the number of people and equipment within the building. The conditions inside buildings are typically defined by the concentration of pollutants such as carbon dioxide, carbon monoxide, ozone and volatile organics, air temperature and humidity, which are all influenced by the level of activity, and the number of people and equipment [90]. The higher density of pollutant sources, higher heat loads along with deeper floor plates and larger buildings often mean that appropriate conditions can be difficult to maintain without mechanical ventilation and conditioning. Conversely the internal density of heat gains from humans and equipment means that if a commercial building is well insulated and well sealed then the requirement for additional heating can be very low.

The fabric of the building has a huge affect on the requirement for mechanical heating, cooling and ventilation, with many commercial buildings built with little regard for the performance of the building envelope. Buildings with a curtain wall façade will have low insulation levels, high solar heat gains, and typically high infiltration rates. These buildings depend on high-energy heating and cooling and ventilation systems to maintain acceptable conditions.

Commercial HVAC systems do three things: generate and deliver heat into the building, extract heat from the building (cooling) and provide fresh air. A commercial HVAC system typically comprises a heat or cooling source (depending on the climate), pumping system to move hot or cold fluids, and air handling and distribution systems for ventilation and to deliver hot or cold air into the space. To minimise the energy requirements for a HVAC system the goal is to:

- minimise the requirement for heating and cooling, through passive building elements
- generate the heating and cooling efficiently
- distribute the heating or cooling efficiently
- minimise the volume of air that needs be moved to maintain ideal indoor air quality
- move the required fresh air efficiently

Small to medium sized buildings typically utilise package-conditioning units for cooling and or heating, or else package-conditioning units for cooling and a gas fired heating system, normally with simple direct user control. For small buildings the technologies used are similar to those used in domestic buildings as discussed earlier, with equivalent upgrade and saving opportunities.

For medium to large buildings, more complicated heating ventilation and cooling systems are used, typically comprising a central chiller (providing chilled water), either air or water cooled (via a cooling tower), hot water boilers, air handling units comprising of fans, motors, air dampers and hot and cold radiators, air distribution systems (duct network), and a range of auxiliary equipment including, pumps, fans, pipe work, valves, sensors, actuators and dampers. HVAC systems are normally supported by a building automation system that coordinates the various components. For many systems the components are operating significantly below current best practice and often contain substances that are now restricted, such as asbestos insulation or refrigerants with high toxicity, ozone depleting potential and global warming potential (see appendix 8). Further to this, poor system integration, losses in auxiliary equipment, lack of maintenance, sub-optimal control strategy and oversized plant with poor part load efficiency typically result in low overall efficiency and too often poor air quality and thermal comfort with in commercial buildings [91].

Retrofit options and improvement strategies

For new buildings, passive design and high-performance glazing, minimising unwanted solar heat gain in summer and maximising heat gain in winter when heating is required, along with comprehensive insulation and a tightly sealed building envelope can practically eliminate the requirement for dedicated heating plant and drastically reduce the cooling requirement relative to a typical commercial building. Further to this, holistic integrated design with attention to detail at every step including the construction and commissioningof the system can deliver dramatically improved performance in HVAC systems and often achieve a significant reduction in equipment sizing. For existing buildings the opportunities to enhance the building envelope through improved building sealing, increasing insulation and improved glazing can significantly reduce the heating and cooling requirements, are equivalent to those described earlier[89]. Upgrade of the equipment that generates heating and cooling ie boilers and chillers, is typically relatively straightforward and is achievable with minimal disruption to the building and occupants, with 2-4 fold efficiency improvements possible. Modification to the air and fluid distribution systems can be challenging or cost prohibitive due to the integration of these components into the building fabric and fit out: for example, duct work is typically integrated into the building structure and hidden behind ceilings and floors, meaning major modifications can require re-fit out of the space. Finally tuning, enhancement or upgrade of the systems that controls and integrate the various components within the HVAC system is readily achievable within an occupied building [92].

Unlike domestic buildings, commercial buildings typically have a bespoke HVAC systems particular to the individual building, meaning that improvements in energy efficiency need to be carried out on a case by case basis depending on the age, design quality and level of maintenance within the building. Due to the invisible service that HVAC systems provide, their complex and specialised system architecture and their tendency to be hidden from view, many systems are performing well below their potential with significant opportunities for improvements in energy efficiency and quality of service delivery.

Although the system design and the current state of the system is unique to each building, these general points are applicable:

All buildings using gas heating should be upgraded to an electric heat pump, this will result in an 80% reduction in the energy required to generate heat. In Victoria, typically as much as half of a building's total energy demand is for heating and domestic hot water requirements, as such replacing the gas boiler with a high-efficiency electric heat pump system could reduce total building energy by around 30%. In cooling only climates where cooling accounts for around 60% of total building energy consumptions, similar savings of around 30% of total building energy could be achieved through doubling the efficiency of the cooling plant.

5-20% total building energy savings can be achieved in buildings up to 5 years old with modern plant and equipment and control systems, through effective and tuning and commissioning. Often this crucial step is either ignored or under-funded in construction projects, as the builder is not responsible for the operation costs of the building.

10-30% total building energy savings can be achieved in buildings 5-10 years old through comprehensive re-commissioning, ie ensuring that all of the system components are operating as designed, updating of control strategies to best practice and updating of the building operating schedule to reflect current use along with minor upgrades such as the addition of variable-speed drives (VSDs) to fans, pumps and cooling towers. Many small changes to the controls strategy and time schedules along with component and temperature set point drift and failure over time can result in large increases in energy consumption. Recommissioning of buildings is recommended every two years and typically has a return on investment of less than one year, see case study below.

10-35% savings in building 10-15 years old can typically be achieved through implementing the above strategies, supplementing the building automation network, minor modifications to air handling systems to facilitate economy cycles and night purge and where required integrating plant and equipment that has been added over the life of the project, for example, coordinating the control of package air conditioning units that may have been added, with the central conditions systems.

15-50% total energy savings are possible for building that are 15+ years old that have not undergone any significant upgrade and have not been maintained to a high standard. Large savings can be realised through a coordinated upgrade of out dated plants along with updating of out dated control systems and commissioning to current best practice.

Reduce internal heat loads by using efficient lighting and powered equipment.

One thing common to all buildings is the importance of good system control and integration, with an out dated but well maintained system able to out perform a modern system that has been poorly commissioned and maintained [93].

HVAC System components

Cooling Plant

At the core of any cooling plant is a heat pump, which is described above. A typical chiller service life is 15-25 years of operation. Therefore, chiller upgrades will be a logical refurbishment option for buildings built in the 1980 and 90s where the chillers are due for an upgrade anyway. Further to this many chillers are operated using refrigerants that are now restricted under the Montreal protocol and are becoming less available for servicing purposes. Modern electric chillers typically have high COPs, meaning that less energy is required to produce the same amount of cooling. Further to this, older chillers typically managed variable loads by staging multiple chillers or by stop-starting a single chiller, where as modern chillers typically have variable-speed compressors that facilitate superior turn down capabilities allowing variable and part loads to be effectively and efficiently met. For larger chillers, peak COPs are often achieved at part load, where most chillers spend the majority of their oper ational hours. In some cases VSDs can be retrofitted to an existing fixed speed chiller to provided greater flexibility and improve part load efficiency without the need for a complete upgrade.

Some features of modern chillers that have facilitated the increase in COP include low-friction magnetic bearings leading to increased efficiency and longer service life, multiple high-efficiency brush-less DC motors with two-stage centrifugal compressors and integrated VSDs allowing for staging in electric motor start up and running. This has seen a two- to three-fold increase in chiller COPs, with older models operating at a COP of around 1-3, to modern chillers achieving COPs of greater than 7 at peak load and greater than 10 at partial load [93]. As noted above, further improvements in performance can be achieved for water-cooled chillers by optimising condenser water temperatures at partial loads, with COPs of 13 being achievable. This represents at least a doubling in efficiency, meaning that less than half the energy is required to deliver the same amount of chilled water. Modern chillers also utilise refrigerants with low ozone-depleting potential (ODP)and lower global-warming potential (GWP) refrigerants, with moves towards using carbon dioxide as a refrigerant which has an ODP of zero and a GWP thousands of times less than many refrigerants currently in use. Carbon dioxide is particularly suited to hot water heat pump systems.

Direct-expansion chillers

Smaller chillers such as direct-expansion (DX) units, use the cooled refrigerant directly via a heat exchanger cool the internal air, which is then distributed around the building. The term DX distinguishes a system from those chiller-based systems which first cool water, and then use a secondary heat exchanger to cool the air. For a DX unit, the condenser must be located close to the evaporator to cool the building. Direct expansion units typically have limited load flexibility and the size of the unit needs to be well matched for the demand. Care must be taken to ensure sufficient air flow is maintained over the evaporator coils, which can limit the use of variable-fan-speed strategies and economy cycles. Where the demand and load are consistent the DX approach is simpler and reduces cooling losses relative to chilled water systems as there is one less heat exchange step.

Variable Refrigerant Volume

Variable refrigerant volume (VRV), also known as variable refrigerant flow (VRF), systems also use the refrigerant directly to cool the air. However, by varying the volume of refrigerant moving between the condenser and evaporator based on demand, greater flexibility can be achieved and larger areas, such as the floor of a larger building or multiple floors of a small building, can be cooled. The advantage of these two systems is that they can be readily deployed off the shelf and can accommodate mixed cooling requirements within a building such as where a single server room requires continuous cooling. A dedicated system or part of the VRV can service this load while the rest of the system is off. Further to this, many VRV systems are able to provide heating and cooling, as such the existing chiller and boiler could be replaced by a single high-efficiency system in appropriate buildings. This option may be cost-prohibitive in buildings that currently use a chilled-water distribution system.

Chilled-water systems

Larger buildings often use chilled-water systems where the cooled refrigerant is used to cool water. The water is then distributed around the building to heat exchangers. This extra conversion step reduces the efficiency of the system, however, it allows greater flexibility for variable demand and allows centralisation of cooling plant with the chillers being able to be located remote from the cooling demand. Centralisation facilitates the use of cooling towers to water cool the chillers, increasing the COP.

Cooling Towers

Larger chillers, particularly those used in multi-storey buildings rely on cooling towers to help reject heat out of the building. A cooling tower is a heat-rejecting device that uses evaporative cooling to reject heat from a water-cooled chiller or process. Cooling towers work by blowing air through a wet chamber causing evaporation and cooling, cooling warm water from the condenser (chiller) down typically around 29°C. Energy is consumed in the fan and the water pumps that circulate the water between the tower and the chiller. Water is also lost through evaporation. Many cooling towers operate with a constant-fan speed regardless of the heat-rejection load. Energy savings can be achieved through the installation of a VSD to the fan motor, with the fan speed to vary in response to demand. The power required to run a pump or fan is proportional to the cube of the speed. This means that if 100% flow requires full power, 75% flow requires 42% of full power, and 50% flow requires 12.5% of the power, thus even small reductions in fan speed result in significant savings in power. The VSD itself consumes a small amount of power. However, when combined with an appropriate control system, significant savings can be made by adjusting the fan speed to meet the required demand. VSDs can also extend equipment life and reduce maintenance requirements by allowing a ramped start up rather than the abrupt start up and high starting torque associated with single-speed drives[93]. VSDs are a relatively inexpensive retrofit to cooling towers.

Further energy savings within the chilled water system can be made by adjusting the condenser water temperature to maximise chiller efficiency at partial load. This strategy can deliver large energy savings at chiller part load, which is the primary operation setting of most chillers, however, it can result in increased water consumption.

In hot humid conditions, effectiveness can be degraded to the point where the cooling tower is a net consumer of energy, ie the heat rejected is less than the fan and pump energy required. In such situations, using the low-humidity, pre-cooled exhaust air from the building can be an important strategy to maintain efficiency (see 'Heat Recovery' below).

Absorption Chillers

Cooling can also be provided by absorption chillers which convert heat, typically hot water into cooling. Absorption chillers have much lower COPs than electric chillers with singe-effect absorption chillers that utilise hot water less than 100°C, having COPs around 0.7, and double-effect hot water absorption chillers that require higher water temperatures achieving COPs of 1.0-1.1 [79].

Air handling systems

General description. Air handling systems are responsible for moving air around buildings, delivering fresh outside air into the building, removing air contaminants and often providing conditioned air to heat and/or cool the air within the building. Air handling systems typically include outside air intakes and exhausts, fans to move the air, hot and/or cooling coils/radiators and ductwork to deliver the air around the building. When no heating or cooling is required the primary purpose of air handling systems is to ventilate the building, providing outside air and removing pollutants [90]. The major determinants of energy consumption in this operating state are the pressure losses through the duct system and the efficiency of the fan motor.

Improving efficiency. For existing buildings modifying the existing ducting to improve the efficiency of the system can be logistically and cost prohibitive due to the integrated nature of ducting into the space. However significant reductions in energy consumption can be achieved through ensuring the appropriate amount of air is being moved through the system. In many older buildings, fans operate at constant speed regardless of the ventilation, heating or cooling requirements of the building. Trough the use of VSD on fans, efficient utilisation of outside air and monitoring of air quality in the space, fan speeds can be optimised to allow large fan-energy savings (as noted a 25% reduction in fan speed delivers a 42% energy saving) while maintaining air quality and conditions.

Fresh air and return air. When heating or cooling is required, a combination of outside air and return air from the building is blown over radiator coils containing hot/ cold water or refrigerant to condition the air entering the space. Savings in the amount of hot or cold water can be achieved through the optimisation of the mixture of outside and return air. For example, buildings that have large outside air intakes can utilise cooler outside air to cool the building when conditions are appropriate. Alternatively, if outside conditions are unfavourable, then outside air can be restricted to the minimum required for ventilation and conditioned air from the building can be mixed with outside air to provide appropriate temperatures and air quality. In many older buildings, the outside air intakes are sized for minimum fresh air only, restricting the potential of utilising favourable outside air conditions for conditioning of the building. The use of outside air for conditioning is described as *economy cycles.* Buildings with the ability to bring in significant amounts of outside air also utilise night purge cycles, which is the process of introducing cool nighttime air to flush accumulated heat out of the building reducing the cooling requirement for the next day, thus improving comfort and reducing peak cooling demand. The effectiveness of night purging is influenced by the thermal mass of the building. Buildings with economy systems consistently require less energy and provide improved indoor air quality [79]. The re-use of return air can be be sometimes improved by UV treatment.

Set points. Another approach to reducing the heating and cooling energy requirement is optimisation of building temperature set-points, for example raising summer cooling set-point from 22 °C to 23 °C can reduce cooling energy by around 6%. Many buildings operate at a fixed set point year round which does not take into account the different occupancy clothing between summer and winter.

Also a widening of heating and cooling set points reduces the incredibly wasteful occurrence of heating and cooling systems fighting each other to maintain tight temperature set points.

Air Distribution Systems

There are a large number of configurations for air handling and distribution systems. In older buildings constant-volume air handling systems are common. In many cases these systems can be modified to variable-volume systems, through the addition of VSDs to fans and integration into the building automation system. In simple systems, where hot and cold air is delivered to zones at a constant volume, air volumes can be adjusted based on the heating, cooling and ventilation requirements, with reduced volumes supplied when conditions are appropriate. One configuration found in older buildings is the hot and cold duct systems where hot and cold air streams are generated at the air handling unit, which are distributed around the building in separate 'hot and cold ducts before being mixed at the delivery point to deliver the required air temperature. This system is inherently inefficient requiring both hot and cold air to be generated and increasing friction losses by forcing air through two sets of ducts [79]. Such systems can be retrofitted to quasi-variable air volume (VAV), through the addition of VSDs to the air handling units and reconfiguration of heating cooling coils and field mixing boxes. This upgrade removes the need to simultaneously generate hot and cold air and can reduce the total volume of air required to condition the building. In many buildings, further reduction in fan power consumption can be achieved through upgrading of belt-driven fans with high-efficiency direct drive-motors (efficiency >90%). This reduces the belt/pulley/bearing/ guard losses, typically >5% of motor energy.

Variable Air Volume

More modern buildings commonly utilise VAV air handling systems. A typical configuration for a VAV system is a central air-handling unit with a VSD-controlled fan and cooling coils. Based on the requirements of the building, variable volumes of air are supplied into the building spaces, with VAV boxes in rooms or zones that control the amount of air entering the space using a damper and a pressure sensor. VAV boxes can include heating coils or electric reheat, for reheating of cooled air or heating of the area. A well-designed and operated VAV system allows for the optimisation of the amount of air being delivered to the, space, minimising the fan energy required, with very low volumes of air (very low-energy consumption) possible when conditions are appropriate. VAV systems typically allow flexible and effective utilisation of economy cycles.

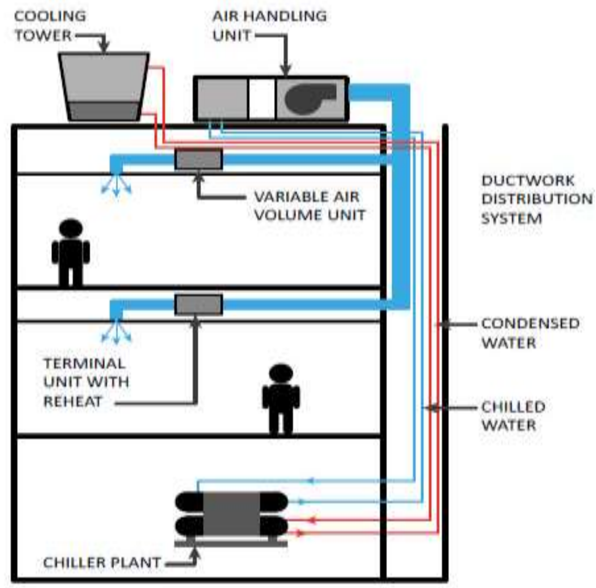

FIGURE 3.21

Components of a central air-conditioned systems [Energy Efficiency & Renewable Energy (US DoE)]

Fan-Coil Units

Another conditioning element commonly used in modern buildings is the fan-coil unit. Cold and/or hot water or refrigerant is distributed throughout the building where many small fans blow either ducted fresh air from a central air-handling unit or air drawn directly from the room over heating/cooling coils to deliver conditioning to the space. Fan-coil units can deliver effective conditioning to buildings and provides flexibility where there is significant variation in conditioning requirements within the building. Fan-coil units readily facilitate the use of occupancy sensors to allow the turn down or switch off of individual fan-coil units when the area is unoccupied. As it is more efficient to pump liquid than gas, fan coil units can reduce the energy required to condition a space by reducing the amount of air that needs to be pumped around a building, whilst still moving the required amount of thermal energy. Due to the reduced duct work requirement, retrofitting of fan coil units can be less invasive than other options. A disadvantage to this approach is that the reduced volumes of air reduces the effectiveness of economy cycles, which in temperate climates can result in increased cooling requirements compared to VAV systems.

Displacement Ventilation/Underfloor

Another air distribution/conditioning method being utilised in modern buildings is under-floor displacement ventilation, where air is delivered through vents in the floor and then drawn off at ceiling level. The advantage of this system is the effective turn over of air, with stale warm air rising up and being removed. Another advantage is that heated air is delivered at floor level where occupants are, allowing low-pressure air distribution. These systems are commonly used with exposed slabs, which can provide thermal mass to help moderate temperatures and reduce peak demand. Many displacement systems use radiant cooling in the form of chilled slabs or chilled beams, which provide cooling at ceiling level, reducing the volume of air that needs to be moved to condition the space. Also chilled slabs can be pre-cooled to reduce peak demands. Retrofitting of underfloor distribution systems is only possible where there is sufficient floor to ceiling height to accommodate the raised floors.

Natural/passive Ventilation

Passive/natural ventilation or mixed-mode ventilation is also utilised in commercial buildings, most commonly in smaller buildings or buildings specifically designed for this purpose. The advantages of utilising natural ventilation is that it reduces the reliance on fans for ventilation and allows direct use of favourable outside air conditions. Unfortunately unless a building has been designed to incorporate natural ventilation, retrofitting is typically complicated and often has limited success if it is not mechanically assisted, 'mixed- mode ventilation'. Passive ventilation has great potential to reduce HVAC energy requirements if ideal outdoor conditions prevail, however, when outside conditions are outside of those acceptable for comfort, for example in the peak of summer, the difficulty of maintaining sufficient control over passive ventilation systems can result in increased conditioning energy consumption.

Heat Recovery

A major source of energy loss from buildings is the exhaust of conditioned air. Optimising the volume of air moving through the building is a crucial first step to minimising these losses. An additional option is the installation of a heat exchanger or enthalpy exchanger to capture some of the energy invested in the exiting conditioned air and provide it to the incoming air. Heat exchangers can take many configurations, such as a series of metal plates where the exiting air is in contact with one side of the metal and the incoming air the other, allowing the transfer of sensible heat between the two air streams [91]. Other methods use wheels containing heat-absorbing materials, liquids and/ or desiccants to allow the exchange of energy between and humidity between incoming and outgoing air. For example, in summer when cool dry air is exhausted from the building, a heat exchanger or enthalpy wheel can be cooled and/or dried by the outgoing air and then used to cool and dry the incoming air, reducing the amount of cooling required to reach set point. The introduction of a heat-recovery system increases the fan energy of the system, and can add additional pumping energy where a heat-exchanging fluid is used. It also requires the exhaust air and fresh air to be co-located or for an additional pumping system to transfer the energy between the two air systems. Therefore it is important that the volume of air being conditioned is optimised to reduce fan losses.

Integration

For all air-handling systems in existing buildings the major challenge is their integration into the building fabric, making large overhauls expensive and often invasive. That being said, significant savings can be achieved through modification and optimisation of the existing systems to improve occupant comfort and reduce fan energy.

HVAC control upgrades

In larger buildings, HVAC systems are often centrally controlled by a building automation system. The advantages of building automation systems is the ability to coordinate and monitor plant including the ability to schedule the operating times of plant and equipment. For many older buildings it is not uncommon for HVAC equipment to be only locally controlled, which often results in extended or 24-hour operation. The installation of central control into these buildings can result in large energy savings due to reduction in unnecessary operation of HVAC equipment and allow greater control over heating and cooling set points [93]. In buildings with outdated or limited central control systems, upgrading of the control to modern direct digital control, with improved operating strategies such as those discussed above and optimised time scheduling can reduce HVAC energy consumption by over 40% in poorly operating buildings. A modern control system allows integration of all elements of the system and implementation of more efficient control strategies some of which have been discussed above. Control upgrades also typically deliver improvements in indoor environmental quality. Modern Control systems can also be integrated with occupancy sensors (also coupled to lighting) to switch off or turn down areas when not occupied [92]. Enthalpy controls and equipment that can recover latent heat in humid exhaust air, especially from special facilities such as aquatic centres can be big energy savers.

Source: http://decarboni.se/publications/zero-carbon-australia-buildings-plan/3-building-space-conditioning