Research group

High Performance Architecture research cluster, School of Built Environment, Faculty of Arts, Design and Architecture, UNSW

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Executive Summary

The refurbishment of Heating Ventilation Air Conditioning and Refrigeration (HVAC&R) systems in commercial buildings is both a challenge and an opportunity. It is a challenge because commercial buildings, especially the bigger ones, are complex energy systems with high and varying requirements and different operational patterns. It is also an opportunity

1.

A typical HVAC&R system consists of the following main components:

2. State of the art refrigeration and heat generation, distribution and emission systems

The features of all the components described in the previous section and their integration determine the overall performance of any HVAC&R system. Usually lasting no more than 20 to 25 years, HVAC&R systems will have to be replaced or at least upgraded several times during a building's life of 50 to 100 years. Therefore, it is a given fact that a system that was state of the art 25 years ago may no longer be considered

(which is not always the case) and is still operating

Electricity is used for HVAC&R purposes, lighting, Plant equipment produces thermal energy and delivers it to terminal units. Unlike other plant types, heat pumps, which operate on the same principle as chillers (i.e. a refrigeration cycle), can heat and cool a space.

Electrically-driven vapour compression chillers can be air- or water-cooled. Water-cooled chillers use a condenser and a water circuit to reject heat to a nearby sink such as a lake, a pond or a cooling tower. The lower the temperature of the heat sink, the higher the performance of the chiller.

Water-cooled chillers usually reject heat into ambient air via a cooling tower. They are used in medium to large chillers, consume large amounts of water and require regular maintenance. When outdoor conditions are mild and dry, free tower cooling – using the cool outdoor air as a free cooling source – can be used.

chillers and **heat pumps** is

when operating in heating mode. It is characterised

cooling mode, which measures the heat rejected from the building to an ambient heat sink times the energy (usually electricity) used in the compressor to drive the refrigeration cycle. The COP and SEER (i.e., the seasonal EER) are greater than 1.0, so for every electric kWh consumed in the compressor, several thermal kWh are rejected from the building. →

the condenser and evaporator are in contact with. Lower evaporator temperatures result in lower COP, and higher condenser temperatures result in lower COP.

An alternative to the conventional compression chiller is an absorption-based chiller that uses a mixture/ solution chemistry and a heat source. These systems are most effective when a "free" or cheap source of heat is available, for example, solar thermal energy or waste heat. The heat source must be hot enough to drive the system.

Absorption chillers typically range from 50 to 6,000 kW, but smaller units are available from some manufacturers. Their COP is usually much lower than those for compression cycle chillers but can be increased by using more complex and sophisticated

Evaporative cooling, or cooling air through the simple evaporation of water, is an attractive system for dry spaces. It uses no refrigerant and consumes little energy.

There are two types of evaporative cooling: direct and indirect. Direct evaporative cooling (open circuit) puts water into direct contact with air. Warm, dry air is changed to cool, moist air. The outside air heat is used to evaporate the water. Indirect (closed circuit) operates on a similar basis except that it uses heat exchange. The cooled moist air never comes in direct contact with the conditioned environment.

Heat pumps transfer heat by circulating a refrigerant through a cycle of evaporation and condensation. A compressor pumps the refrigerant between two heat exchanger coils. In one coil, the refrigerant is evaporated at low pressure and absorbs heat from its surroundings. The refrigerant is then compressed on the way to the other coil, where it condenses at high pressure. It then releases the heat it absorbed earlier in the cycle.

A heat pump cycle is fully reversible and can provide year-round climate control. Because they use renewable heat sources from their surroundings, heat pumps

and operate most effectively when there is only a small temperature difference between the heat source and heat sink.

Commonly used in air-conditioning and as refrigerants,

because they are potent greenhouse gas, prompting

Ambient air is the most common heat source for heat pumps. Air-source heat pumps draw heat from outside air during winter and reject heat outside during summer.

However, they achieve, on average, 10 to 30% lower seasonal performance than water-sourced heat pumps because of the rapid drop in capacity and performance with decreasing outdoor temperature, the relatively high temperature difference in the evaporator, and because of the energy needed to defrost the evaporator and operate the fans.

There are two types of air-source heat pumps, the most common being the air-to-air heat pump. It extracts heat from the air and transfers it indoors. Air-to-water heat pumps are used in buildings with hydronic heat distribution and emitter systems.

Air-to-air heat pumps include single package systems (window and wall systems, packaged units) and split systems (single split systems, multi-split systems and Variable Refrigerant Flow (VRF) systems). A packaged air conditioning system usually refers to a self-contained system fully integrated into one package. Packaged systems can serve a variety of areas, controlling temperature and humidity. They can be designed for internal and external areas that are restricted by size and affected by noise. Ducted systems are popular, with the ductwork distributing the circulated air throughout the areas served. ➔

Split-air conditioning systems are made up of an outdoor and an indoor unit. The outdoor unit is mounted externally and rejects or absorbs heat as the system requires. The two units are connected via small-bore refrigerant pipework and control wiring.

State of the art systems have an inverter that controls cooling and heating by varying the speed of the compressor and fans, making them much more

Multi-split systems are similar to the single-split system, but they can serve several different rooms by separate indoor units that are matched to one outdoor unit. They can only be used in one mode at a time, heating or cooling, and the outdoor units are fully inverter-controlled, delivering just the right amount of cooling or heating for any room.

An air-to-water heat pump transfers heat from outdoor air to water for space heating or domestic hot water. They are usually all-in-one systems designed to deliver the right temperature for space heating, for domestic sanitary hot water and with the additional advantage of offering air conditioning in the warmer seasons. They have an outdoor unit, an indoor unit (hydrobox) that usually has a backup heater, a domestic hot water tank with an internal electrical heater (optional) and

cooling, fan coils, radiators).

As Australia's electrical grid is progressively decarbonised, air-to-water heat pumps are increasingly competitive and environmentally friendly for heating buildings with hydronic (water) heat distribution systems.

Ground source heat pumps (GSHP) are central systems consisting of one or more heat pumps coupled with a condenser loop or a closed-loop ground heat exchanger, with brine as a medium. In a central system, the heat pumps are located in a single mechanical equipment

terminal units throughout the building. →

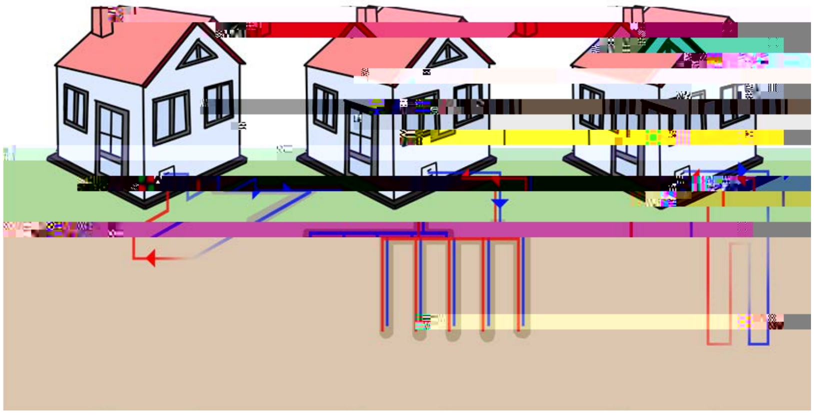


Figure 1. (Left) Horizontal closed-loop system. (Middle) Thermo-active building foundation. (Right) Borehole heat exchanger.

As mentioned above, when a BAC system is integrated with a building's services, it becomes a Building Management System (BMS); Building Energy Management Systems (BEMS) relate to energy

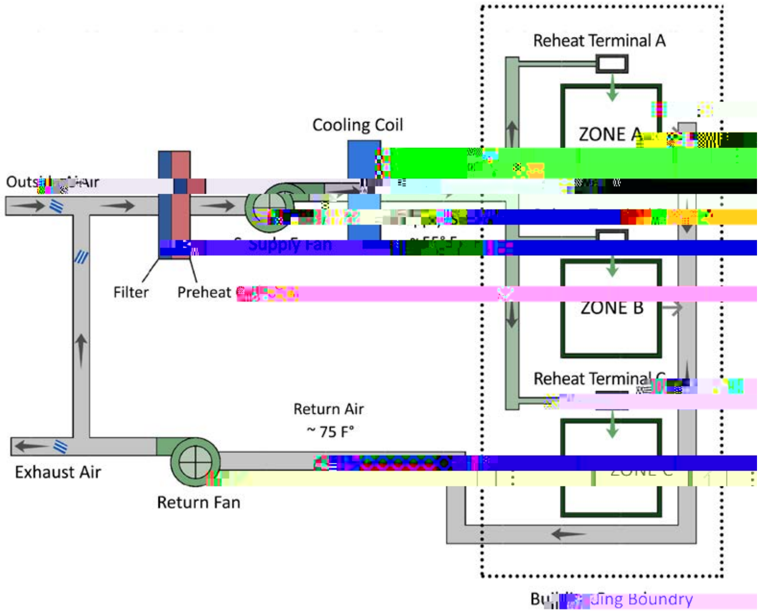
- Heating, ventilation and air conditioning
- Lighting

Table 2. Energy performance factors based on building type for automation and controls used (ISO-EN15232)

Non-residential building types	Electrical e f ciency factors			
	D	C	B	A
	Non-energy e f cient	Standard (Reference)	Advanced energy e f ciency	High energy e f ciency
	1.10	1	0.93	0.87
Lecture halls	1.06	1	0.94	0.89
Educational (schools)	1.07	1	0.93	0.86
Hospitals	1.05	1	0.98	0.96
Hotels	1.07	1	0.95	0.90
Restaurants	1.04	1	0.96	0.92
Wholesale and retail	1.08	1	0.95	0.91
Other types – sport facilities, storage, industrial facilities etc.,		1		

3. Typical HVAC&R systems in the considered building groups

Figure 2. Schematic diagram of typical AHU


Reheat Terminal A
ZONE A
Cooling Coil
Filter
Preheat
ZONE B
Return Air
~ 75 F°
Exhaust Air
Return Fan

VRV/VRF systems with mechanical ventilation

VRV (Variable Refrigerant Volume) or VRF (Variable Refrigerant Flow) systems are more complex and larger variants of ductless multi-split systems. They have several compressors, a large number of evaporators, and sophisticated oil and refrigerant management

to the ability of the system to control the amount of

for the use of multiple evaporators of varying capacities

simultaneous heating and cooling in different zones, and heat recovery from one zone to another.

Two-pipe or three-pipe systems are available. A two-pipe inverter is similar to a multi-system inverter in that it has multiple indoor units of various sorts and sizes. One or more outdoor condensing units serve the inside units, all of which are connected by a single refrigerant piping system.

Multiple interior units are connected to one or more outside units via one set of refrigerant pipework in the three-pipe system, which is identical to the two-pipe system. It employs three independent pipelines between all of the units, rather than two, as the name implies.

VRF systems have numerous advantages and are often regarded as one of the best solutions for commercial building heating and cooling. They can serve many zones, each with its own setpoint control.

VRF systems can maintain precise temperature control because they use variable speed compressors with large capacity modulation capabilities. Duct losses, which are often estimated to be between 10% and

eliminated with the VRF.

Each condensing unit in a VRF system normally has two to three compressors (one of which is variable speed), allowing for a wide range of capacity modulation. Because HVAC&R systems normally operate at 40-80% of maximum capacity, this results

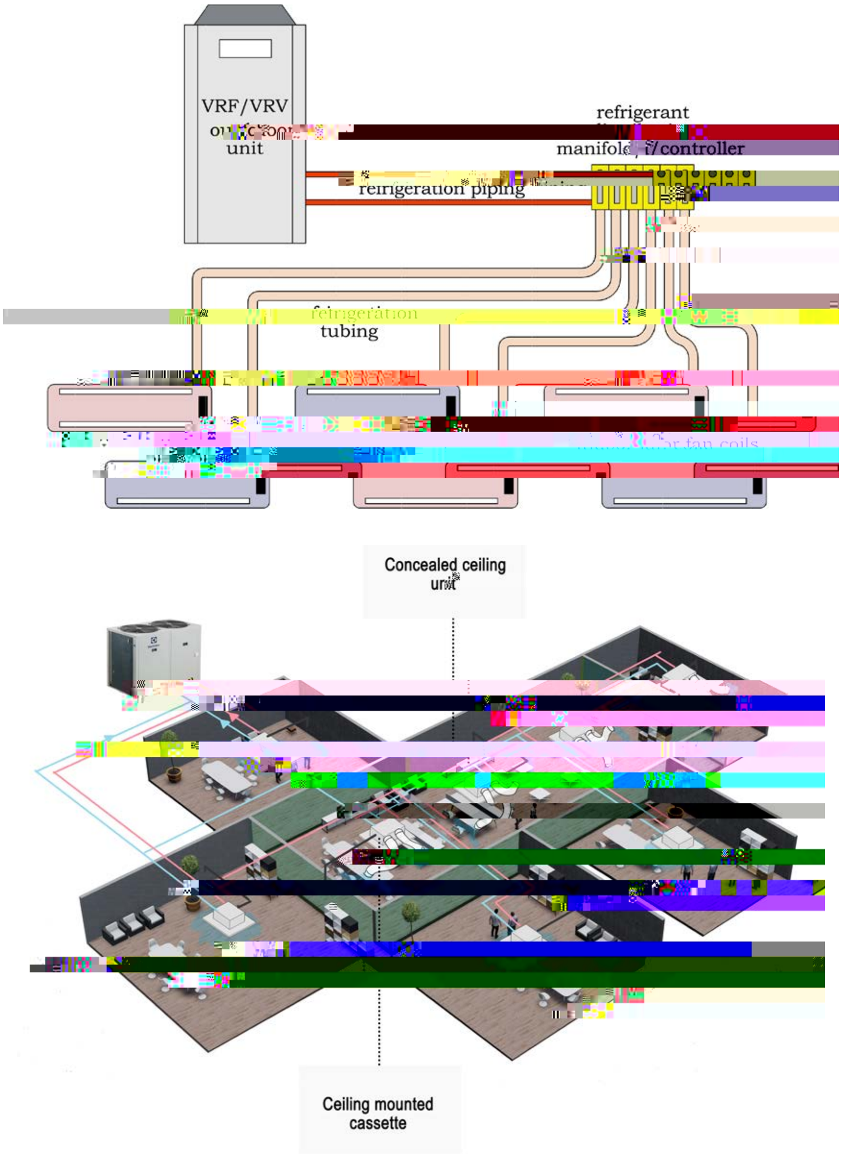


Figure 5. VRF/VRV system schematic diagram and typology

Local HVAC&R systems providing cooling/heating

Multiple zones or a big, single zone can exist in some buildings, necessitating the use of central HVAC&R systems to serve and meet the thermal requirements. Other structures, such as houses and residential apartments, may have a single zone that requires equipment to be located within the zone. This type of system is referred to as a local HVAC&R system since each piece of equipment only serves its own zone and does not cross into adjacent zones (e.g., using an air conditioner to cool down a bedroom or using an electrical heater for the living room). As a result, to activate the local HVAC&R system, a single zone only requires one point control point attached to a thermostat. Multiple local HVAC&R systems serve particular single zones in some buildings and are controlled by the single-point control of the desired zone. These local systems, on the other hand, are not connected to or integrated with central systems, but they are still part of a larger full-building HVAC&R system.

Local air-conditioning systems

Unitary air conditioner

From an equipment standpoint, it is comparable to window air conditioners. It's mounted on the building's

Every room will have a single unitary air conditioner or a central packaged air conditioner that covers different rooms that can be installed. →

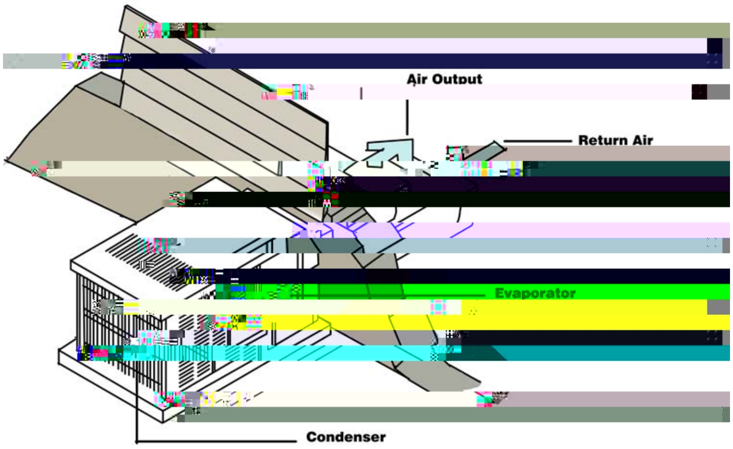


Figure 6. Unitary air-conditioner

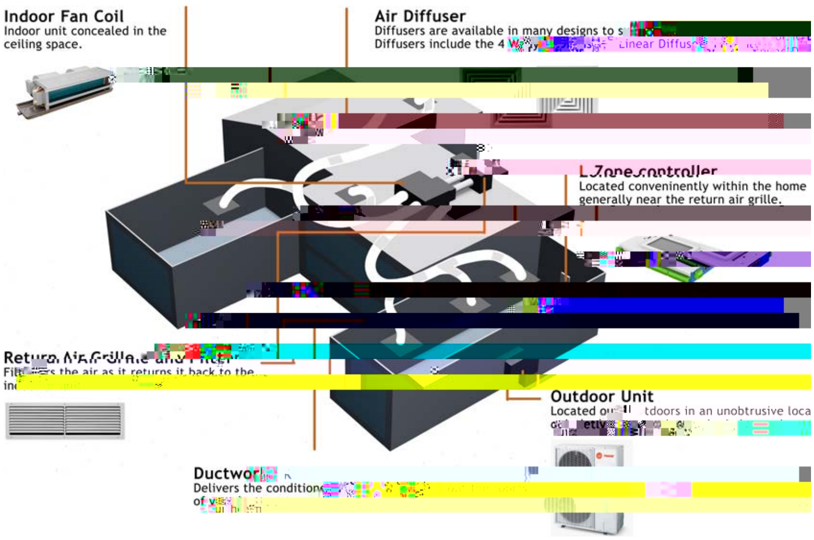


Figure 7. Ducted split air-conditioner

Packaged rooftop air-conditioner

It consists of a vapour compression refrigeration cycle, a heat source such as a heat pump or electric

and control devices. This technology can be connected to ductwork and used to cool a big single zone that unitary or window air conditioners couldn't reach.

Split systems

The condenser, which is positioned outside, and the evaporator, which is located inside, are the two central components in split systems. A conduit for refrigerant lines and wires connects the two devices. Because the location and installation of window, unitary, or rooftop air conditioners might affect the aesthetic value and architectural design of the building, this system addresses several concerns with small-scale single-zone systems. One condenser unit can be coupled to many evaporator units in a split system (multi-split) to service as many zones as possible under the same or different climatic conditions. →

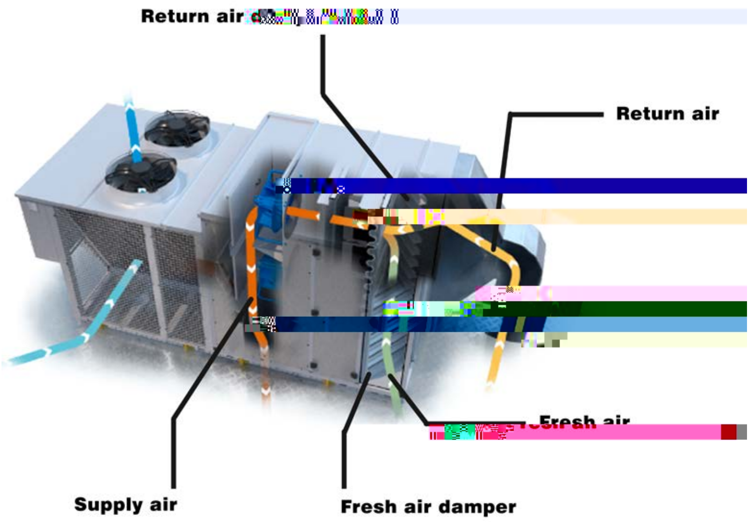


Figure 8. Packaged rooftop air-conditioner

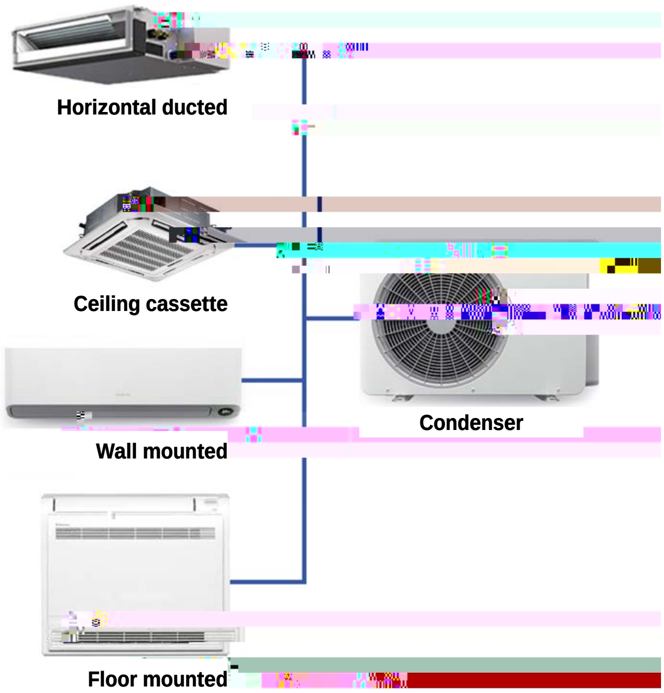


Figure 9. Multi-split system air-conditioner

A series of aspects can determine the refurbishment strategy for a commercial building: the wish to reduce operational expenses, the improvement of indoor conditions, and the reduction of the environmental

In this option, a more holistic approach is taken into consideration. The idea is to upgrade the whole building, both the building envelope and the HVAC&R systems, integrate renewable energy systems and install a Building Management System.

thermal insulation under the existing roof can reduce both heating and cooling loads. In the same context, applying thermal insulation on the external wall will also lead to the reduction of thermal losses, resulting in the reduction of energy consumption. Moreover, another intervention concerning the building envelope is the replacement of the windows with new aluminium

to reduce thermal losses in winter and solar loads in summer and achieve airtightness throughout the year. In this approach, replacing the whole HVAC&R system

one is also suggested. In addition, implementing the Building Management System in accordance with the automation and control systems to interlock the use of HVAC&R, DHW and lighting systems with both the weather conditions and the operational requirements will contribute to the reduction of energy consumption.

Finally, the integration of renewable energy systems is essential in this approach. Photovoltaics can be installed on the rooftops to cover a part of the electrical needs of the building. Concerning the production of DHW, the installation of solar thermal collectors is suggested. The solar thermal system can be either autonomous (the well-known solar water heaters) or a central one with the main storage tank. Moreover, the implementation of heat pumps (ground or air source) for heating, cooling and DHW purposes can be considered.

The deep renovation option, which is clearly the one with the highest initial investment costs, can turn existing buildings into nearly zero-energy ones.

5. Criteria for selecting a refurbishment strategy & the interventions

refurbishment projects in commercial buildings, despite the very appealing feasibility of energy savings, is their operational status: the complexity of leasing arrangements, the varying lengths of tenure and the

in a fair and effective way between the owners and the tenants, make the implementation of otherwise

singly-occupied buildings. Especially when it comes to HVAC&R systems, their refurbishment is linked

with works that have to be examined with respect to

energy and environmental impact. Finally, since such interventions, as a rule, disrupt the HVAC&R's, and hence the building's operation, it is essential to consider the duration of works and the disruption they cause.

According to the procedure of developing an effective and sustainable decision-making framework related to interventions, the following criteria should be considered, as they are presented in Table 4. →

Table 4: Criteria for selecting refurbishment interventions for buildings.

Categories	Parameters examined / Input Data	Tools [illegible]

Especially concerning the HVAC&R system, the following criteria should be examined and evaluated:

Ratio (EER) of equipment

•

marketability, which refers to the potential of a property to be rented fast and at a higher rate and is one of the strongest arguments for an appropriate renovation

marketability applies not only to the commercial value

nurseries and kindergartens to local communities.

Commissioning performed by a third party, including testing and tuning, has an essential role in ensuring the performance of an HVAC&R system and its operation as designed. From “startup”, to “testing, adjustment, and balancing” and then commissioning, are different stages of the whole commissioning

HVAC&R system, delivering thermal comfort to the building. Without measurements, testing and

especially for complex systems. ■