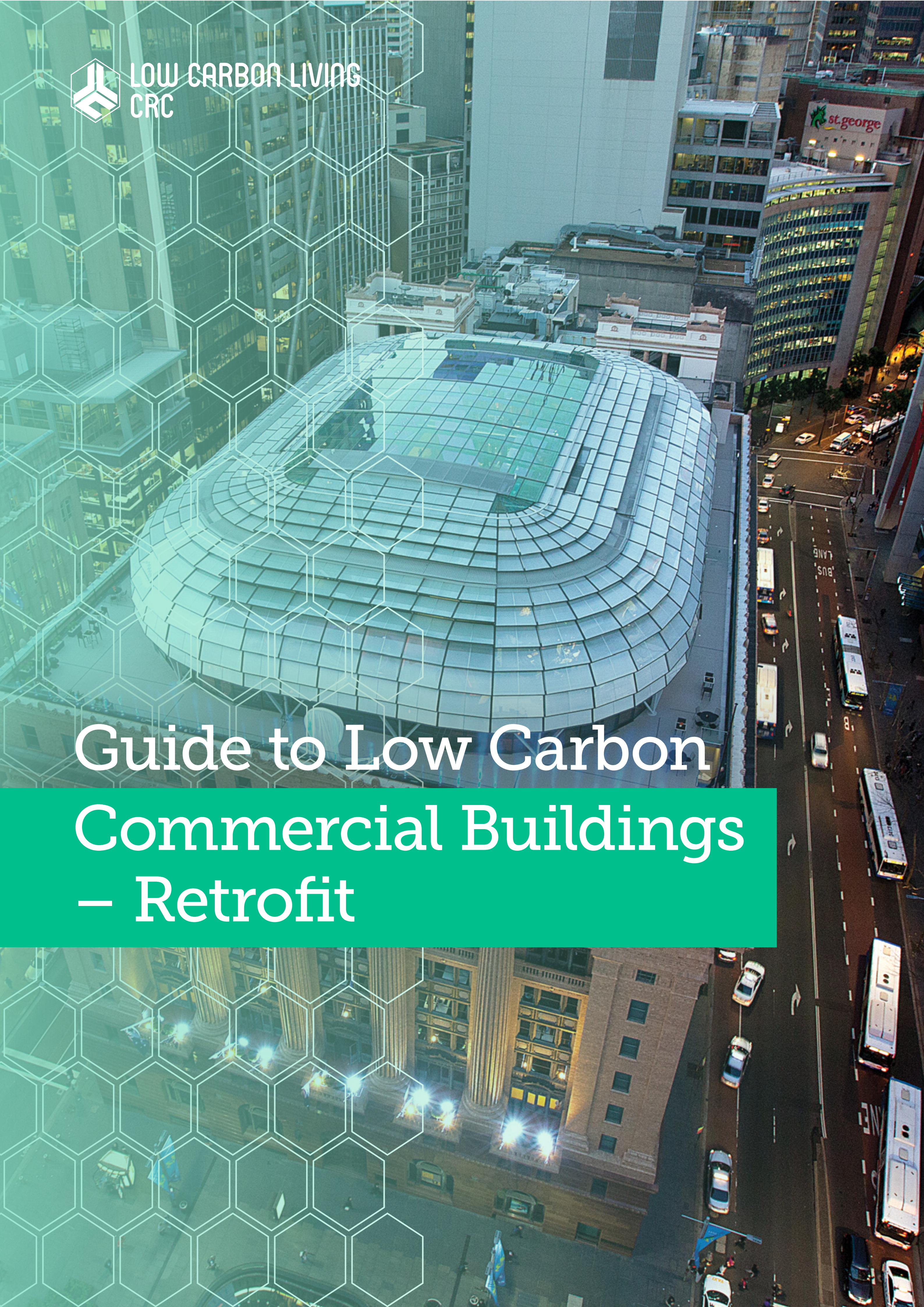
LOW CARBON LIVING CRC



Guide to Low Carbon Commercial Buildings – Retrofit

Acknowledgements

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Glossary

Albedo
An expression of the ability of surfaces to reflect sunlight. Light-coloured surfaces return a large part of the sun's rays back to the atmosphere. Dark surfaces absorb the rays.

ASHRAE
The American Society of Heating, Refrigerating and Air-Conditioning Engineers is an international society advancing human well-being through sustainable technology for the built environment. It focuses on building systems, energy efficiency, indoor air quality, refrigeration and sustainability within the industry.

Benchmarking
The practice of comparing business processes and performance metrics to industry bests and best practices from other companies. Dimensions typically measured are quality, time and cost.

Building envelope
The physical partition between the inside of a building and the external environment, consisting of the building's exterior walls, floor and roof, and exterior doors and windows.

Cool Roof
One that has been designed to reflect more sunlight and absorb less heat than a standard roof.

Embodied energy
The energy consumed by all of the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery.

Emissivity
The emissivity of the surface of a material is its effectiveness in emitting energy as thermal radiation.

Incident solar radiation
The radiant solar energy that hits the earth's surface and is referred as "global radiation" on a surface.

Kyoto Protocol
An international treaty among industrialized nations that sets mandatory limits on greenhouse gas emissions.

Life Cycle Costing
The cost associated with a project from its beginning to the end of its useful life and beyond. It includes the cost of acquiring the project, operating it, and disposing of it at the end of its useful life.

Low Carbon Refurbishment
When a building is refurbished or retrofitted with materials, facilities and energy sources designed and constructed to release as little carbon as possible during the building's lifetime.

Thermal insulation
The reduction of heat transfer (i.e. the transfer of thermal energy between objects of differing temperature) between objects in thermal contact or in range of radiative influence.

Urban heat island
An urban or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities. The temperature difference is usually larger at night than during the day, and is most apparent when winds are weak.

Abbreviations

Abbreviation	Meaning
ACCUs	Australian Carbon Credit Units
AHU	Air Handling Unit
a-Si	amorphous Silicon
µc-Si	microcrystalline Silicon
BAC	Building Automation and Control
BAS	Building Automation System
BEMS	Building Energy Management Systems
BIPV	Building Integrated Photovoltaics
BMS	Building Management Systems
BoS	Balance of System
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
CCTV	Closed Circuit TV
CdTe	Cadmium Telluride
CERs	Certified Emissions Reductions
CFL	Compact Fluorescent Lamp
CH4	Methane
CHP	Combined Heat and Power
CHP	Cogeneration (or combined) of Heat and Power
CIGS	Copper Indium Gallium Diselenide
CIS	Copper Indium Diselenide
CO_2	Carbon dioxide
COP	Coefficient of Performance
CPV	Concentrating Photovoltaics
CRCLCL	CRC for Low Carbon Living
CRES	Centre for Renewable Energy Sources
CRF	Capital Recovery Factor
CRT	Cathode Ray Tube
c-Si	crystalline Silicon
DC	Direct Current
DEFRA	Department of Environment, Food and Rural Affairs
DGNB	Deutsche Gesellschaft fur Nachhaltiges Bauen
DR	Demand Response

E3	Equipment Energy Efficiency
EHS	European Home Systems
EIB	European Installation Bus
EIO	Environmental Input/Output
EPS or XPS	Expanded or Extruded Polystyrene
FMSA	Fooks Martin Sandow Anson
GEMS	Greenhouse and Energy Minimum Standards
GHG	Greenhouse Gas
HFC	Hydrofluorocarbons
HID	High Intensity Discharge
HEQ	High Environmental Quality
ICE	Internal Combustion Engine
ICT	Information and Communications Technology
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IS	Instant Start
ISO	International Organization for Standardization
KNX	Konnex
LCA	Life Cycle Analysis
LCCA	Life Cycle Cost Analysis
LCCE	Levelized Cost of Conserved Energy
LCD	Liquid Crystal Display
LCOE	Levelized Cost of Energy
LCR	Low Carbon Refurbishment
LED	Light Emitting Diode
LEED	Leadership in Energy and Environmental Design
low-e	Low Emissivity
LPG	Liquefied Petroleum Gas
MCFC	Molten Carbonate Fuel Cells
mc-Si	multi-crystalline Silicon
N2O	Nitrous oxide
NABERS	National Australian Built Environment Rating System: Awards a star rating to a building that represents its actual operational performance, based on 12 months of measured energy data.
NCOS	National Carbon Offset Standard
NGOs	Non-Governmental Organizations
NLA	Net Lettable Area
NPV	Net Present Value
NRCA	National Roofing Contractors Association
O&M	Operation & Maintenance

PA	Process Analysis
PAFC	Phosphoric Acid Fuel Cells
PEMFC	Polymer Electrolyte Membrane Fuel Cells
PFC	Perfluorocarbons
PS	Programmed Start
PUR or PIR	Polyurethane or Polyisocyanurate
PV	Photovoltaic
PVT	Photovoltaic Thermal
RMUs	Removal Units
RS	Rapid Start
SAI	SAI Global company
sc-Si	single crystalline Silicon
SF6	Sulphur Hexafluoride
SHGC	Solar to Heat Gain Coefficient
SIPs	Structural Insulated Panels
SOFC	Solid Oxide Fuel Cells
SR	Solar Reflectance
TBM	Technical Building Management
TE	Thermal Emittance
TES	Thermal Energy Storage
UFAD	Underfloor Air Distribution
UN	United Nations
UNEP	United Nations Environment Programme
UPS	Uninterrupted Power Supply
USGBC	US Green Building Council
UV	Ultraviolet
VCU	Verified Carbon Unit
VER	Verified Emissions Reduction
VIC	Victoria
VLT	Visible Light Transmission
VRF	Variable Refrigerant Flow
VRV	Variable Refrigerant Volume
WMO	World Meteorological Organization
WSHP	Water Source Heat Pump
WSP	Wireless Session Protocol

Emissions and the built environment

Buildings, in all their forms, have a huge impact on the environment. Globally, the United Nations Environment Program estimates they are responsible for **30–40%** of all primary energy used.

In Australia, buildings are responsible for one quarter of all greenhouse gas emissions.

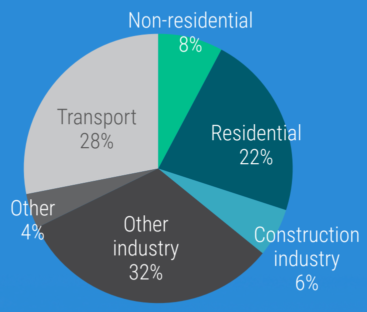
This presents a **significant challenge** as well as a **valuable opportunity** for the built environment sector to contribute to emissions abatement and mitigation.

In 2016, the Australian Government ratified the **Paris Agreement** within the United Nations Framework Convention on Climate Change, pledging to work alongside other developed nations to achieve net zero emissions by 2050 and a 26–28% reduction in emissions relative to 2005 levels by 2030.

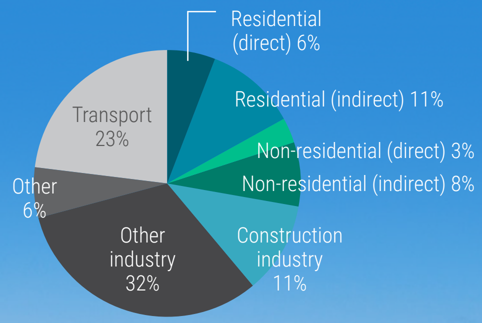
It is clear that if Australia is to achieve these targets, curbing emissions from **the built environment will play a central role**. And with more than 75% of the world's population predicted to be living in cities by 2050, the decisions and actions taken now will have effects decades into the future.

Global share of buildings and construction final energy and emissions, 2017

Energy



Emissions



Source: Derived from IEA (2018a), *World Energy Statistics and Balances 2018*, and *IEA Energy Technology Perspectives* buildings model

About the CRCLCL

The **Cooperative Research Centre for Low Carbon Living** (CRCLCL) is a national research and innovation hub for the built environment. It aims to influence policies and practices to reduce carbon emissions, improve energy efficiency and realise other co-benefits while driving competitive advantage for Australian industry. It has undertaken more than 100 research projects with industry and government partners and supported almost 100 PhD and Masters students.

Supported by the Australian Government and almost 40 industry and government participants, it links leading Australian researchers to organisations across all sectors involved in the built environment. When it ceases operations in mid-2019, the CRCLCL will leave a legacy of research outputs, policy and practice innovation, and enhanced national capacity. This Guide and others in the Low Carbon Guides series form part of that legacy.

A guide for every situation

Each Low Carbon Guide summarises best practice in various phases of the building lifecycle—construction, retrofit, operation—for a range of building types in the residential and commercial sectors and at the level of precincts. The series includes:

Guide to Low Carbon Residential Buildings – New Build
Options for homeowners, builders and designers during the planning and construction of new homes.

Guide to Low Carbon Residential Buildings – Retrofit
Retrofit solutions for existing homes, tailored for homeowners and their contractors.

Guide to Low Carbon Households
Advice to homeowners and renters on operating households using low carbon living approaches.

Guide to Low Carbon Commercial Buildings – New Build
The design and construction of low carbon commercial buildings.

Guide to Low Carbon Commercial Buildings – Retrofit
Methods for retrofitting commercial buildings to improve performance while reducing energy and carbon use.

Guide to Low Carbon Precincts
Frameworks and options to assist councils and developers with strategic planning decisions when implementing low-carbon neighbourhoods.

Further Guides cover Landscape, Urban Cooling, Value-chain and other topics.

For further information go to: builtbetter.org/lowcarbonguides

Introduction

Why refurbish commercial buildings?

Building owners and managers and their commercial tenants are increasingly recognising that adopting energy efficiency, renewable energy and other sustainable practises in commercial buildings makes good business sense.

The benefits of "decarbonizing" commercial buildings include lower energy bills, and greater staff productivity and happier customers thanks to healthier indoor environments. Reducing a building's carbon footprint can also help building owners and managers comply with government regulation, and create a corporate identity that embraces sustainability, a concept that is increasingly popular with staff and customers.

In Australia, the commercial building sector is expected to account for 10% of Australia's total greenhouse gas emissions by 2020. For that reason, the Australian Government's energy efficiency program includes measures designed to make it easier for building owners and tenants to make informed choices about their energy use and invest in better buildings and equipment.

Challenges and opportunities

Those who embark on a low carbon refurbishment (LCR) of a commercial building face challenges and opportunities, and will need the support and cooperation of property owners, managers and tenants. But LCR also represents new business for everyone from surveyors and energy consultants to architects, engineers, and suppliers.

Ensuring refurbished buildings meet standards for environmental sustainability, energy efficiency and indoor environmental quality will require the involvement of inspectors, trainers, accreditation bodies and regulators.

Dollars and sense

The tools, technologies and policies needed to make commercial buildings more sustainable are already in place but if LCR is to be widely adopted the commercial property market must be convinced it adds value to existing buildings.

If commercial property owners believe LCR is an investment that will yield higher returns down the track they will be more likely to embed the concept into every part of their business, and seek out information about decarbonisation technologies and strategies.

It can be difficult to predict and verify exactly what LCR will do for your bottom line. A building's performance must be assessed before any changes are made and that can take time and money. Building managers must also understand the implications of any retrofit for their tenants.

A study of the emissions reduction opportunities in commercial buildings carried out on behalf of the Australian Carbon Trust in 2010, for example, showed that a lack of information was impeding emissions reductions across the sector.

However, other studies show that if commercial property owners can be convinced it is in their long-term interests, they will find the capital to fund LCR works.

To produce a solid business case, refurbishment measures must be priced accurately, and the impact of any retrofit on operating and maintenance costs fully understood. It must also be clear how a retrofit helps an organisation achieve its corporate goals and meet tenants' expectations.

Environmental rating systems such as the Building Research Establishment Environmental Assessment Method (BREEAM) and the Leadership in Energy and Environmental Design (LEED) are vital for organisations that want to demonstrate the value of an LCR to themselves and the market.

SECTION

01

Methodology

Successful low carbon refurbishment of commercial buildings requires appropriate financial assessment and advocacy, the identification and implementation of best available technology solutions and the use of benchmarking and certification tools to verify what is planned and built.

Making a case for LCR

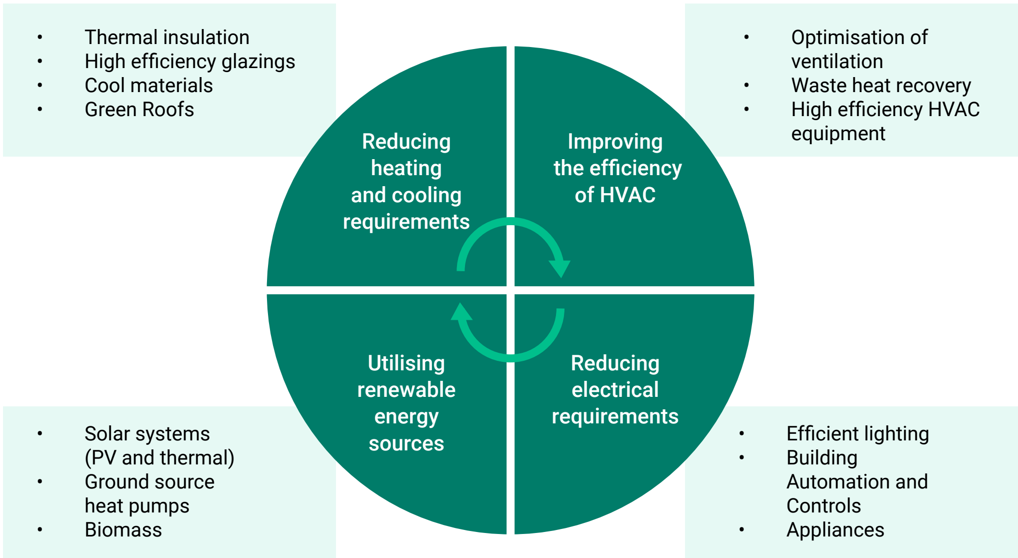


Figure 1.1 There are four distinct areas where changes can be made.

Advances in technology and design are making it increasingly easy for new buildings to achieve small carbon footprints.

However, existing buildings can also make great strides to decarbonize and it often makes more sense economically and environmentally to retrofit a building than demolishing it to make way for a new one.

Installing thermal insulation and more efficient heating, ventilation and air-conditioning (HVAC) systems and heat pumps, and sourcing a building's power from renewable energy, for example, can easily help decarbonize a building.

Energy consumption accounts for up to 80% of a commercial building's carbon footprint and it is here that some of the biggest sustainability gains can be made.

Owners and managers can measure a building's energy efficiency, among other things, by using the Federal Government's National Australian Built Environment Rating System (NABERS). The system awards star ratings to buildings, from one star (poor) to six stars (market leading), based on an analysis of 12 months' energy use.

A building's *embodied* energy – the energy consumed by all the processes associated with the production of a building – can also be reduced by using more recycled, less energy-intensive materials and optimizing product design to use as little material as possible.

The amount of land and water used by a building, and the amount of waste it generates can also be measured and addressed.

Whether or not a building is refurbished to cut its carbon footprint will depend on what it costs and how long it takes to recoup that cost. In the best case, that analysis would be based on the costs incurred from the beginning of a project to the end of its useful life.

Building owners and managers usually undertake LCR to cut operational costs and to make the building more attractive to tenants. An organisation's corporate social responsibility policies, such as taking action on climate change, are also motivating factors.

Making the most of the best technologies

There are four areas where changes can be made to an existing building: the building envelope, heating and cooling systems, electrical equipment, and renewable energy.

The most efficient refurbishment plan will use the best technologies in each of those areas, as illustrated in the figure below.

Building owners are sometimes reluctant to undertake LCR in buildings that have more than one tenant because of competing interests between them and their lessees. The complexity and varying lengths of leases, and the uneven sharing of any expected benefits from LCR make it more difficult than retrofitting a building that has only one tenant. Owners can also be reluctant to refurbish a building that is fully occupied because of the disruption it causes to tenants.

The duration of works and the disruption they cause must be factored into any LCR plan, whether it be regular maintenance or a complete refurbishment or "deep renovation", as illustrated in the table below:

Some changes can be made to multi-occupied buildings with little or no disruption to tenants, such as raising awareness about how to save power and water and reduce waste, and upgrading maintenance schemes. Likewise, building managers can easily measure and monitor the energy used by air conditioners and heating plant to see where savings can be made; and they can clean HVAC diffusers, grilles and filters to improve air quality and reduce losses.

Types	Typical works	Impact on tenants	Duration of works
Maintenance	Regular maintenance of HVAC systems	None	1 - 3 days
Minimal	Minor repairs to restore building envelope and HVAC systems to mint condition	Minimal; can be done outside office hours	A few days, depending on the scope
Minor	Upgrading HVAC systems, including central plant, common area, external elements of building envelope	Some disruption from plant replacements. Services may be temporarily unavailable. Minimal impact on tenants	From 3 to 6 months, depending on type of systems
Major	Replacement of central plant and all elements noted above. Glazed facades, lighting, air conditioning, etc., upgraded. Façade elements, suspended ceilings, floors replaced	Depends on type of systems, e.g., central plant, floor by floor, separate wings.	
Tenants must vacate	Depending on the case, six to 12 months. Requires significant licensing and approvals from authorities.		
Total	Strip back to basic load-bearing structure, remove all façade elements, HVAC systems	Tenants must move out	1 to 2 years. Requires similar level of approvals to that of a new construction

Benchmarking and Certification

Benchmarking a building's performance against other buildings can also help. Benchmarks can be based on averages or percentiles of real performance, or on a policy-driven objective such as achieving 'net zero carbon'.

Any carbon target must be defined by a quantitative goal to be reached by the end of a project; it can be absolute, for example, in tons of CO_2 equivalent, or it can be based on a comparison with averages in the building's sector. Basic benchmarking steps are depicted in the figure below.

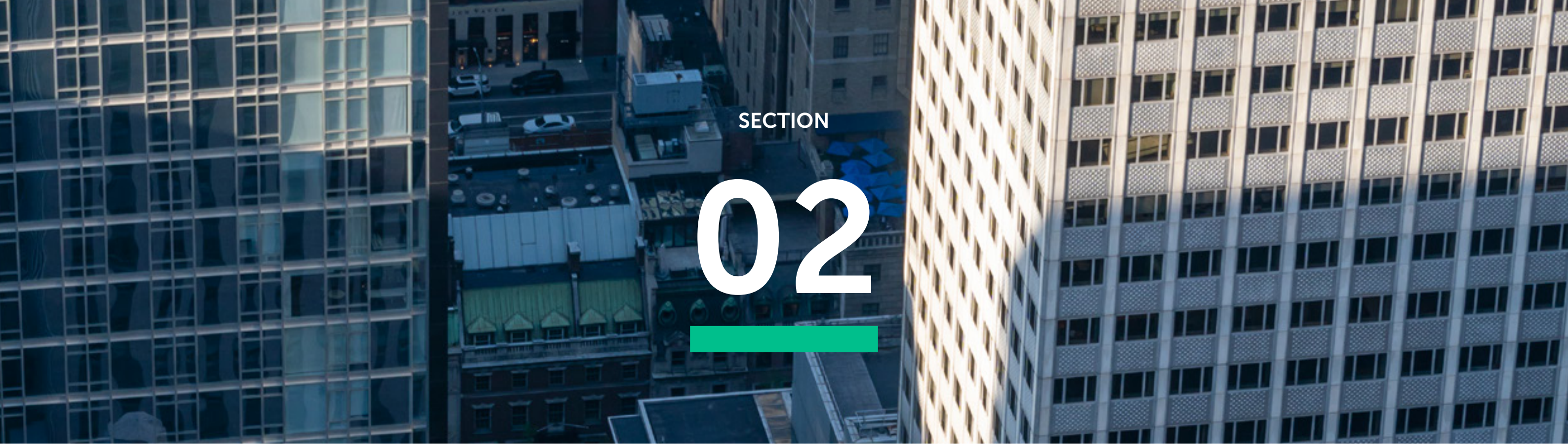
It is important to choose the appropriate indicators that measure performance, for example, kilowatt hours per square metre or kilograms of CO_2 equivalent per customer.

There are various tools and approaches that can be used to assess the sustainability and energy performance of a building, such as NABERS for new and existing buildings, the National Carbon Offset Standard (NCOS), which is a voluntary standard to manage greenhouse gas emissions; and BREEAM, an international sustainability assessment method for master planning projects, infrastructure and buildings.

Tools that only measure and benchmark a building's energy performance, such as Energy Star, can be used as a first step towards a more comprehensive sustainability assessment.

All of these kinds of ratings also provide simple, useful ways to explain the value of sustainability to the public.

Figure 1.2 Benchmarking for sustainability process



SECTION

02

Reducing demand, improving efficiency

Efficiency, sustainability and low emissions can be pursued in all parts of the building envelope, from the roof and cool materials to advanced glazings and in all parts of the building services, from HVAC to lighting and automation and controls.

The Building Envelope

Insulation: Reducing thermal losses

In 1973, the "first oil shock" sent oil prices soaring globally and pushed heating oil out of reach for many people. Builders and renovators turned their attention to insulation to help warm homes and buildings.

Nearly 50 years on, insulation remains a highly effective tool to reduce energy consumption and it plays a major role in the drive to make buildings more energy efficient.

Insulation is primarily used as thermal insulation to reduce heating and cooling costs. However, depending on the materials used, it can also protect against fire and noise, an important consideration for commercial buildings.

Insulation is most valuable in regions where significant temperature variations occur, particularly in cold climates, because it can prevent heat escaping from buildings.

Insulation is less effective when it comes to cooling buildings because much of the sun's heat is transferred via glazed surfaces. However, insulating exposed surfaces, such as flat roofs, can improve thermal comfort.

Insulation can do more than just heat and cool a building:

- **Fire Insulation**: Commercial buildings, in particular, public buildings, must be made fire-resistant. Various materials can be used to slow or contain the spread of fire through a building, providing more

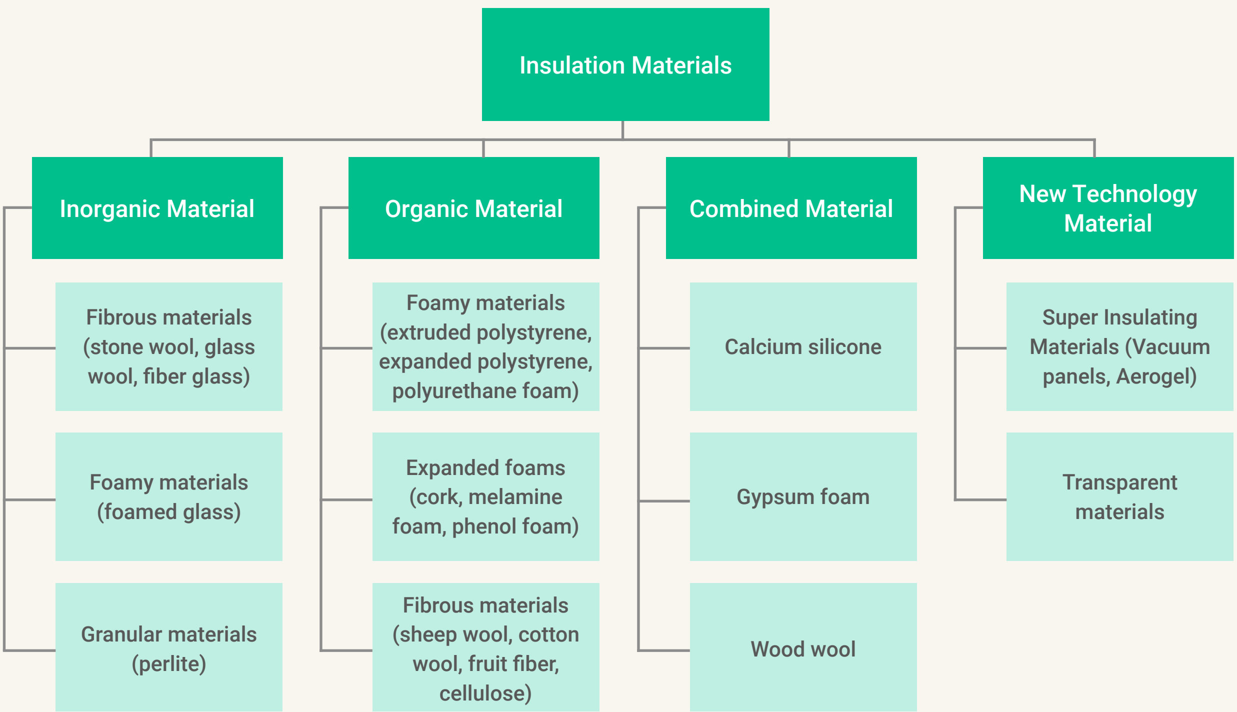


Figure 2.1 Categorisation of insulation materials

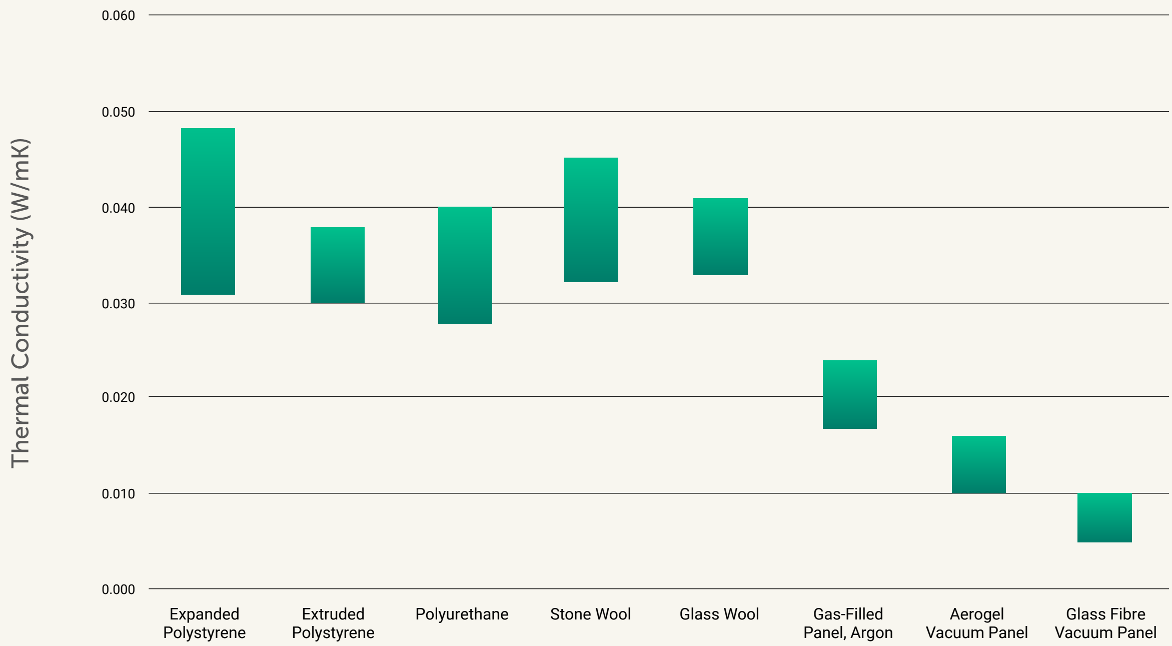


Figure 2.2 Categorization of insulation materials

time to evacuate building occupants and limiting damage to the building.

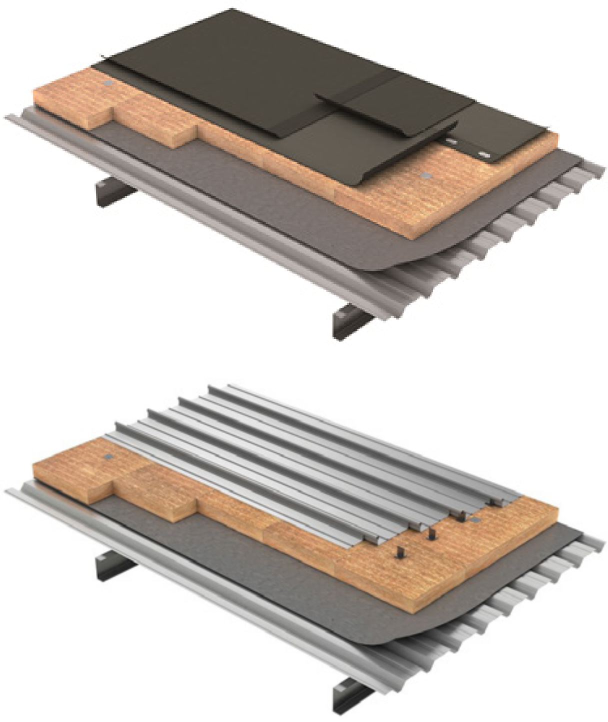
- **Acoustic insulation**, or soundproofing, can improve the acoustics within a room, and reduce sound leakage to or from adjacent rooms, in particular, low frequency noise.

- **Impact insulation**, or cushioning, protects buildings from shock and vibration. It is especially important in industrial and manufacturing buildings where vibrations can damage the structure of the building. It is also import in any building that caters to large crowds because of the risk of damage from anthropogenic vibrations.

Insulation materials can be organic or non-organic, fibrous or foamy. The type and nature of the insulation will determine its ability to conduct heat.

Insulation can be broken down into the following groups:

- **Blanket insulation** – batts and rolls - is the most common and widely available type of insulation. It is usually made of inorganic material such as fibreglass, stone wool or glass wool, but can be made of organic materials such as cotton or wool.



Top: Flat roofs can be insulated with rigid stone wool plates with a bitumen-coated fibreglass face. Bottom: Rockwool used on a standing seam metal roof.
Source: Rockwool

Below: Spraying PUR foam on a flat roof. Right: What it looks like when the job's done. Photos: Reeves, National Roofing Contractors Association

- **Foam boards**, or rigid foams, are stiff panels of insulation that work well in exterior wall sheathing, and interior sheathing for basement walls and attic hatches. They are made of expanded or extruded polystyrene and/or polyurethane (PUR) or polyisocyanurate (PIR) foam.
- **Rigid fibrous boards** are made of stone wool, glass wool or fibreglass and are used when building materials need to withstand high temperatures.
- **Concrete block insulation**: The core of a concrete block can be filled with insulating material such as polystyrene, PUR or PIR.
- **Loose-fill insulation** is often used when a building is being refurbished because the foam or flakes of fibrous material can fit any space. For example, foam can be blown into the cavity between double brick walls.
- **Structural insulated panels** (SIPs) are prefabricated insulated structural elements that can be used in building walls, ceilings, floors and roofs. In commercial units, they are usually made of galvanized steel and filled with PUR/PIR foam or, when fire resistance is required, with stone wool or glass wool. In the image below, structural insulating metal sheet panels have been filled with PUR foam and stone wool.

The application of as little as 5cm of insulation material to a building element can cut thermal losses by more than 60% and, generally, there is little variation between different types of insulation material (although super-insulating materials are available).

So, the selection of materials must be based on other criteria, such as fire and water resistance, high tensile strength, or a material suitable to surfaces with complex geometry. If there are no specific criteria for the project, cost will determine which material to use.

Cool roofs

We often think of insulation as something we put inside a building but materials used on the exterior of a structure also play a major role in thermal conductivity. A "cool roof" is designed to reflect more sunlight and absorb less heat than a standard roof. There are all kinds of ways to cool a roof. Special materials can be added to tiles, claddings and cement, and roofs can be painted a "cool" white.

Top: Cool paints can easily be sprayed on a flat roof. Bottom: They can also be applied to roof-top HVAC equipment, increasing its efficiency.
Photos: Jobe Roofing, Thermoguard

Typically, white reflective coatings contain transparent polymeric materials, such as acrylic or PUR, and a white pigment, such as titanium dioxide that makes the paint opaque and reflective. The pigments absorb some of the incident solar radiation and protect the polymer material and the substrate from UV damage.

The two basic characteristics that determine the coolness of a roof are its solar reflectance index (SRI) and thermal emittance (TE).

There is a great variety of cool paints available, with SRI values ranging from 0.4 to 0.85, and TE values of more than 0.85.

Cool materials can keep surface temperatures 20 to 40°C cooler than conventional roofs, and can cut the temperature inside a house by between 3 and 7°C. Those lower temperatures can reduce the cooling energy requirements for office buildings by between 5 and 20%, and for retail stores by between 7 and 17%. Those reductions are especially important in the case of typical galvanized steel roofs, often found in commercial buildings.

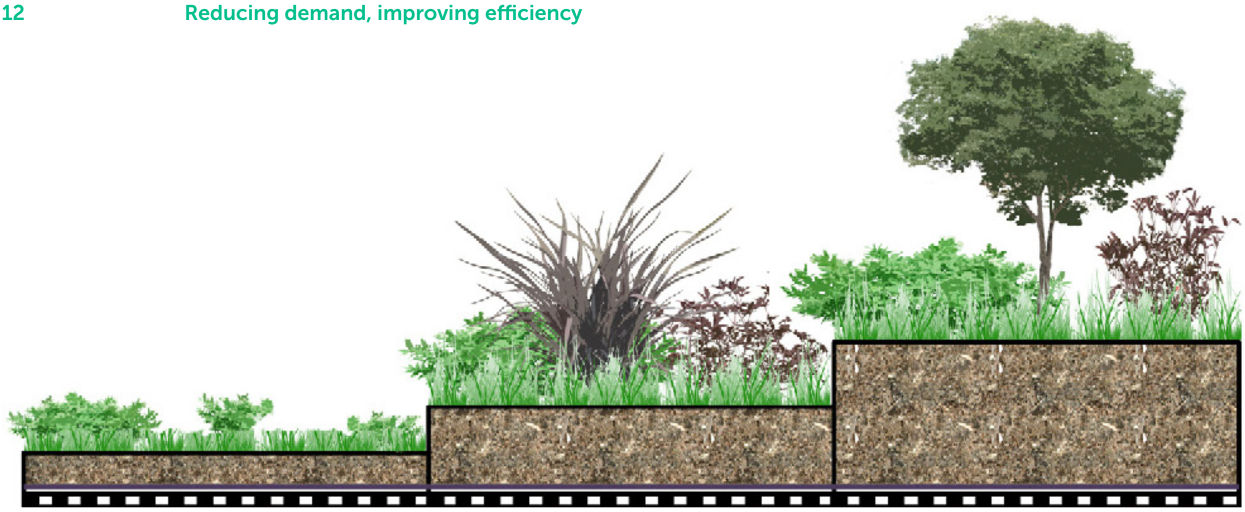
A cool roof coating is probably one of the most cost-effective ways to improve the energy efficiency of a commercial building and to refurbish it at the same time because it reduces the expansion and contraction cycles that lead to premature failure of underlying membranes.

It is worth considering the properties in different "cool" paints before choosing one.

- **Acrylic coatings**, which suit most climates, are water-based, highly reflective, UV resistant, and easy to work with. They are usually the most cost-effective choice. However, they age faster and don't perform well when water pools on a roof.

- **PUR coatings** are more traffic and impact resistant and handle stress better. There are two main types: aromatic and aliphatic. Aromatic coatings are less expensive but are not UV-stable; aliphatic coatings are UV resistant, durable and stay cleaner than most other coatings. However, they are more expensive.

All cool paints age thanks to the accumulation of dirt and microbiological factors on roofs, potentially cutting



Extensive Green Roof	Semi-Intensive Green Roof	Intensive Green Roof
Height 6 – 20 cm	**Height** 12 – 25 cm	**Height** 5 cm > 1 m
Weight 60 – 150 kg/m²	**Weight** 120 – 200 kg/m²	**Weight** 180 – 500 kg/m²
Vegetation Mosses, sedums, herbs and grasses	**Vegetation** Grasses, herbs and shrubs	**Vegetation** Lawn, perennials, shrubs and small trees
Cost Low	**Cost** Low	**Cost** High
Maintenance Low	**Maintenance** Periodically	**Maintenance** Regularly

Figure 2.3 Types of green roof.
Source: R. Fernandez-Cañero, T. Emilsson, C. Fernandez-Barba (2013), "Green roof systems: a study of public attitudes and preferences in southern Spain". Journal of Environmental Management, p128, p106-15.

their albedo by between 25 and 30% after four to five years, depending on the climate and air pollution. Regular maintenance will prolong a paint's life.

Green roofs

Green roofs have become increasingly popular in recent years because they can reduce storm-water runoff, noise and air pollution, help cool buildings, increase the longevity of roofing membranes, sequester carbon, and provide a habitat for wildlife.

They can also improve the look of a building. They are particularly well suited for existing buildings, and can help mitigate the surrounding urban heat island.

There are three types of green roofs: intensive, semi-intensive and extensive.

Intensive roofs feature a thick soil layer and can support a wider variety of plants but they are heavy and need a lot of maintenance. Extensive green roofs have a thinner layer of soil and lighter vegetation. They require less maintenance but still provide environmental benefits. Semi-intensive green roofs combine features from intensive and extensive roofs.

Green roofs can reduce a building's cooling load by between 2 and 10% (depending on the building type) because the soil provides thermal insulation and the evaporative transpiration by plants cools the air near the roof. The soil and vegetation also help protect the roof from thermal stress and extreme weather.

There are disadvantages to installing a green roof, especially on an existing building. The weight of the soil and vegetation could exceed a roof's permitted static loading; and irrigation, fertilizer, maintenance and water-proofing costs can be high. Also, caring for water intensive plants can significantly increase a building's water bills.

A Green roof on a 1970s office building in Amsterdam retrofitted in 2012. Photo: ZinCo Green Roof Systems

Advances in glazing

Thermal losses in the commercial sector were cut significantly when builders started adopting double- and then triple-glazing last century.

But since then, more advanced types of glazing have been developed, such as low emissivity (low-e) glazings. When glass is covered with a microscopically thin, transparent coating it can reflect long-wave infrared energy and, in some cases, short-wave solar infrared energy.

State-of-the-art low-e glazing can have an emissivity factor as low as 0.02, compared with 0.82 for clear glass, making them a powerful tool in reducing a glazed façade's thermal losses, in summer or winter, depending on the location of the coating.

Double glazed, low-e windows and glass facades can significantly reduce heating and cooling requirements. On average, they can cut the total annual energy requirements of an office building that has a large window-to-wall ratio by between 8 and 15%, compared with conventional double glazed windows.

Low-e glazing's inability to respond to variations in daily solar radiation prompted the development of dynamic glazing, or smart windows, which respond to environmental conditions. Made of photochromic material, the glass changes transparency automatically in response to light intensity, similar to the way eyeglasses can change from clear to dark when the wearer walks into bright sunshine.

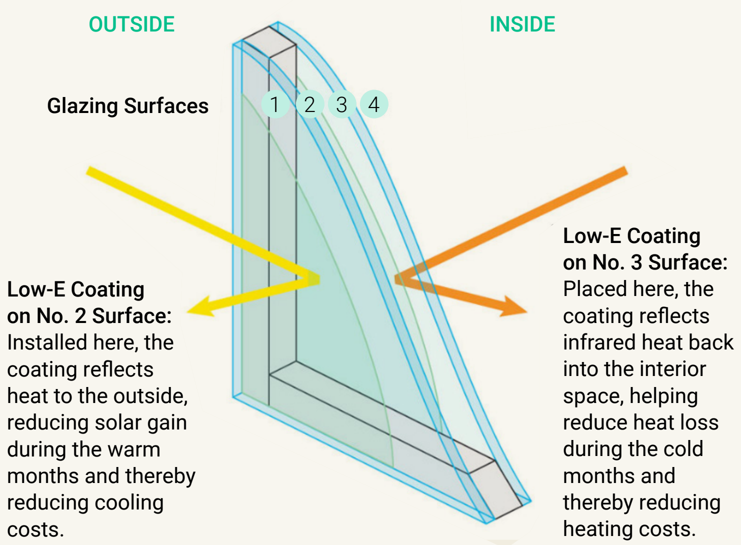


Figure 2.4 How low-e coated windows work.
Source: Vitro Architectural Glass

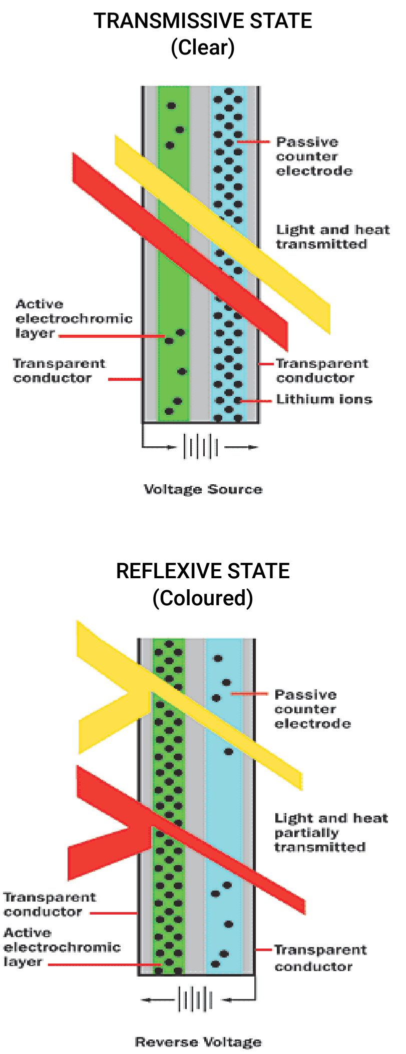
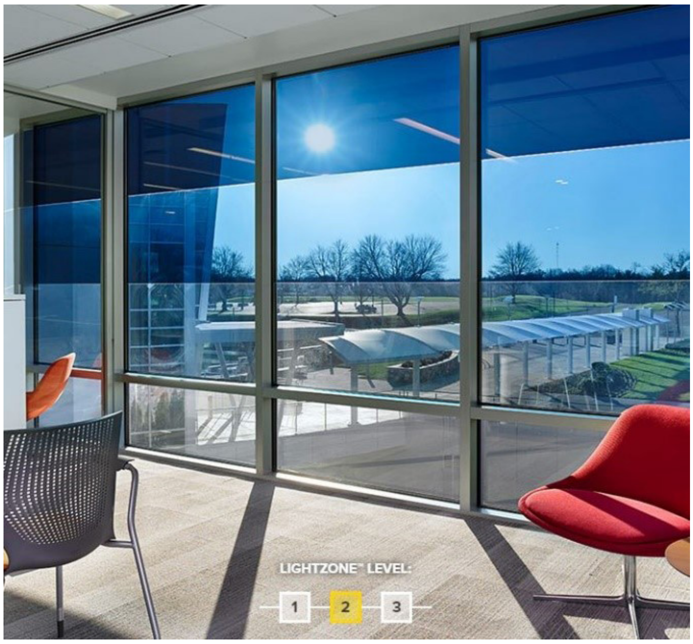


Figure 2.5 How electrochromic glazing works.
Source: LBNL

What electrochromic glazing looks like in a commercial setting.
Photo: Giroux



Existing façade elements can be easily fitted with photochromic glazing and it is not much more expensive than low-e glazing. There are drawbacks, however, such as unwanted activation, which can reduce their performance over time.

The glazing can also be controlled electronically, allowing building occupants to change how much light is transmitted through windows and glass doors. When darkened, electrochromic glass can block up to 95% of solar radiation, dramatically lowering the amount of air-conditioning a building needs – up to 20% of the electricity used in commercial buildings, or up to 10% of a building's total energy consumption, according to a 2013 study by the US National Renewable Energy Laboratory.

Electrochromic glazing can also be combined with advanced automation systems to create the perfect environmental conditions at the lowest cost.

However, this kind of glazing has drawbacks. It can be twice as expensive as photochromic glazings and up to four times the price of low-e glazing. Also, more work needs to be done to ensure this kind of glazing can last longer than 15 to 20 years.
Also, some glazing can take several minutes to change from clear to opaque, and back again.

Generally, however, low-e glazing can deliver big energy savings to commercial buildings, with pay-back periods of between five and eight years.

Dynamic glazings provide HVAC savings of between 6 and 19% above those offered by standard high-performance windows. They remain expensive and have some teething problems but the technology is expected to play a significant role in the next decade.

Heating, Ventilation and Air-Conditioning

HVAC systems don't just heat and cool buildings; they also control humidity and ventilation.

An HVAC system is generally made up of plant equipment, a delivery system and an emission system.

- The plant equipment is characterized by its energy source (e.g. fossil fuels, solar energy), and its form (e.g. chemical, electrical) before it is converted into thermal energy in the plant.
- The delivery system refers to the heat medium (e.g. air, water, refrigerants) that is being used to transfer the thermal energy from the plant to the emitters inside the building that will transmit the thermal energy around the building.
- The emission system is characterized by its heat transfer mode (e.g. convection, radiation).

Some of these components can be omitted or combined in one entity, for example, electrical infrared heaters don't need a heat distribution system and combine the plant and the emitter in a single piece of equipment.

Some systems have thermal energy storage (TES) between plant equipment and a distribution system, which acts as a buffer or longer term storage.

The overall performance of any HVAC system is determined by the features of all three subsystems and their integration.

Usually lasting no more than 20 to 25 years, HVAC systems will have to be replaced or at least upgraded several times during a building's life of 50 to 100 years. This represents a great opportunity to improve energy efficiency and accommodate advances in building technology and regulations, such as the emerging smart electrical grid and smart meters.

HVAC subsystems

Plant Equipment: →	Delivery System (medium type): →	Emission System (heat transfer method):
• Energy Source	• Air	• Convection
• Energy Form	• Water	• Radiation
	• Refrigerant	• Combination
	• Steam	
	• None	

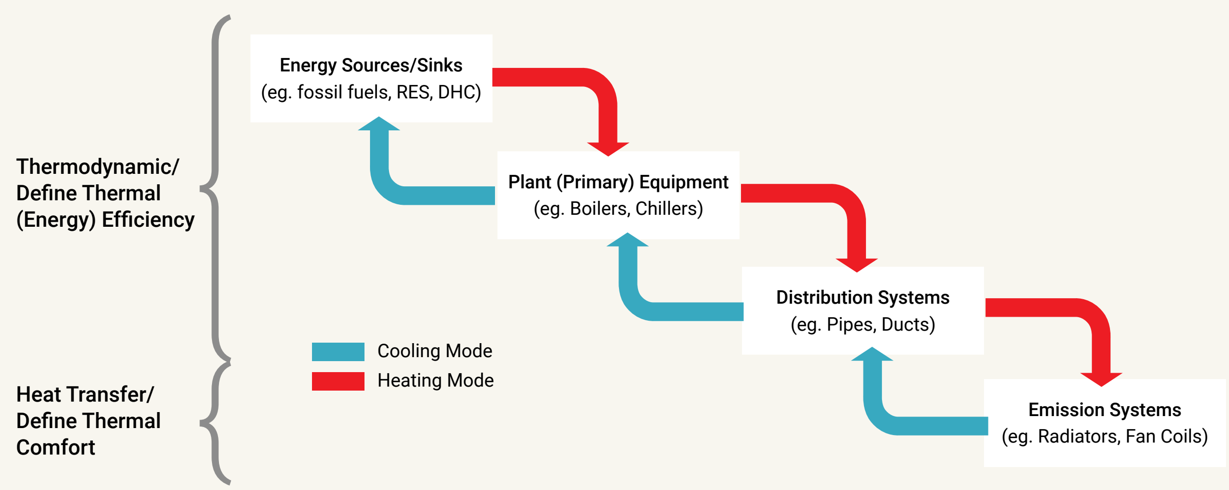


Figure 2.6 The components of building energy systems.
Source: Mattheos Santamouris 2019

Heating and Cooling Terminal Units

Heating and cooling terminal units maintain a building's indoor environment at a desired level of thermal comfort. As illustrated below, these units can be divided into several groups:

- **Forced air systems** directly control indoor air temperature, although they cannot guarantee comfort in all cases because of variables other than air temperature.
- **Radiant systems** control surface and air temperatures, and have more complex controls but create better comfort at lower air temperatures, in turn, further reducing heat loss via infiltration and ventilation.

Radiant systems – hydronic and electric – supply most of their thermal energy via radiation. They do not centrally mix air, so ventilation needs to be provided mechanically or naturally. Electric radiant systems, which convert electricity to thermal energy, are less efficient than other systems and used only for heating.

Hydronic systems, especially embedded building elements such as heated floors, directly heat and cool buildings and the people in them, and only indirectly heat or cool indoor air. They can also store excess thermal energy, which can be used off-peak. These systems can be difficult to install but have little impact on a building's overall architecture.

These kinds of systems don't use extreme temperatures, so they can be fed by highly efficient

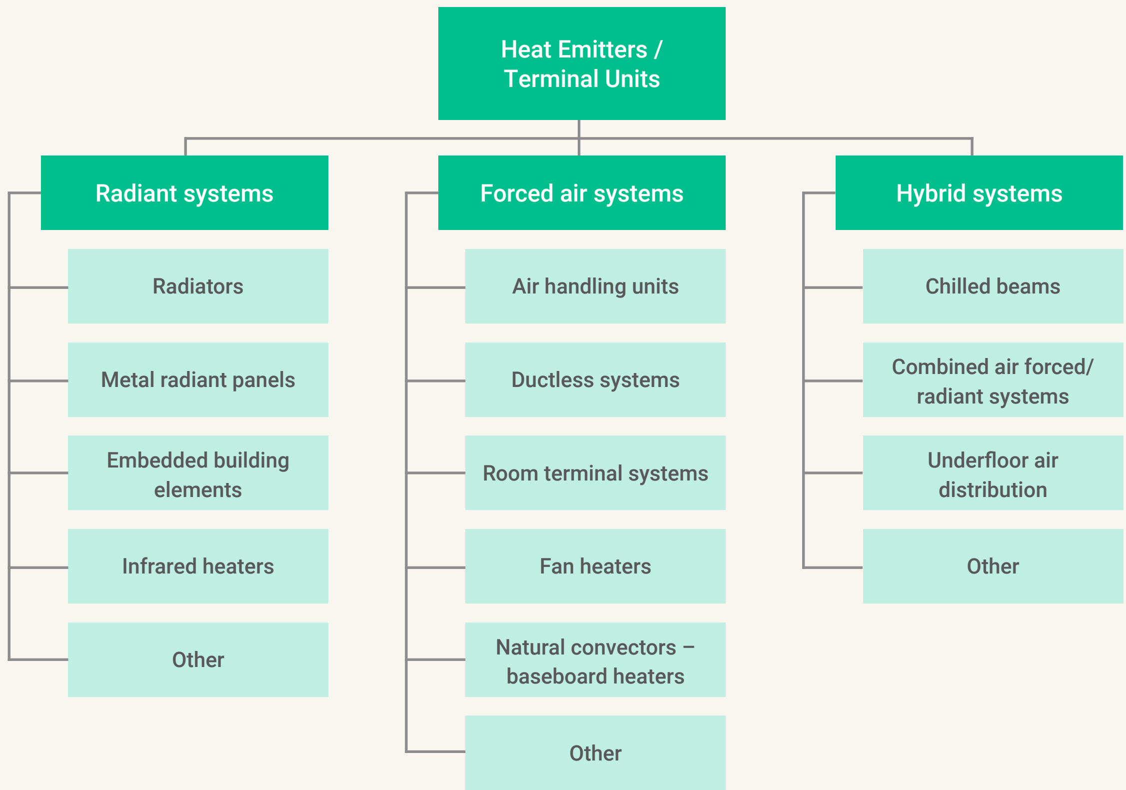
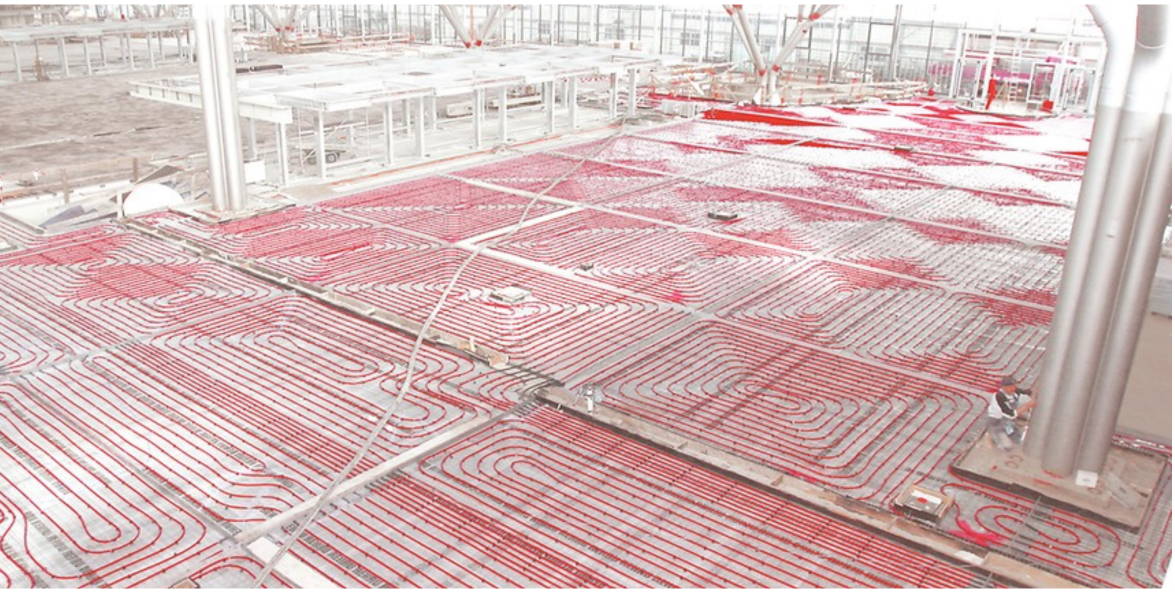


Figure 2.7 The range of heating and cooling terminal units.
Source: Mattheos Santamouris 2019



Left: A floor heating and cooling system being installed. Photo: Rehau
Below: Chilled beams in an office ceiling space in Birmingham use water to remove heat energy from the room. Photo: chilled-beams.co.uk

plant equipment, such as heat pumps. They are also quieter because they don't use fans.

Infrared heaters are another kind of radiant system, suitable for some niche heating applications. Converting gas or electricity to heat and operating at medium to high temperatures, they don't heat indoor air, and can be directed to heat one portion of a building, making them very suitable for large spaces such as airplane hangars, factories, warehouses and gymnasiums, and even open areas such as loading docks or stadiums.

Forced air systems include air handling units (AHU), room terminal units, ductless systems, natural convectors and baseboard heaters and fan heaters.

AHUs can provide all the latent cooling, preheating, and humidification required by a building. Heating is either provided by the main air stream of the central system or locally at specific spaces. They are classified into single- and dual-duct categories as well as constant and variable volume categories.

Conditioning depends on air mass flow rate and temperature difference between supply and room air. The variable volume systems are throttling back flow when less heating/cooling is required and the reduced flow results in reduced fan energy. Variable temperature systems change the temperature of supply air as thermal loading conditions change. In general, variable volume systems are considered more energy efficient.

All air systems display a high degree of flexibility in their configuration and can precisely control indoor

air temperature and humidity. However, they take up a large amount of space in a building., and their energy performance can be undermined by auxiliary energy consumption from the fan.

Room terminal systems condition spaces by distributing air and water sources to terminal units installed in habitable spaces throughout a building. They allow for more individualized control of different spaces while any ductwork is smaller than the all air systems because it mainly handles fresh air.

Room terminals can be made up of induction units or fan coil units. In an induction unit, centrally conditioned primary air is supplied to the terminals while secondary flow is drawn into the terminal through a secondary coil for further conditioning.

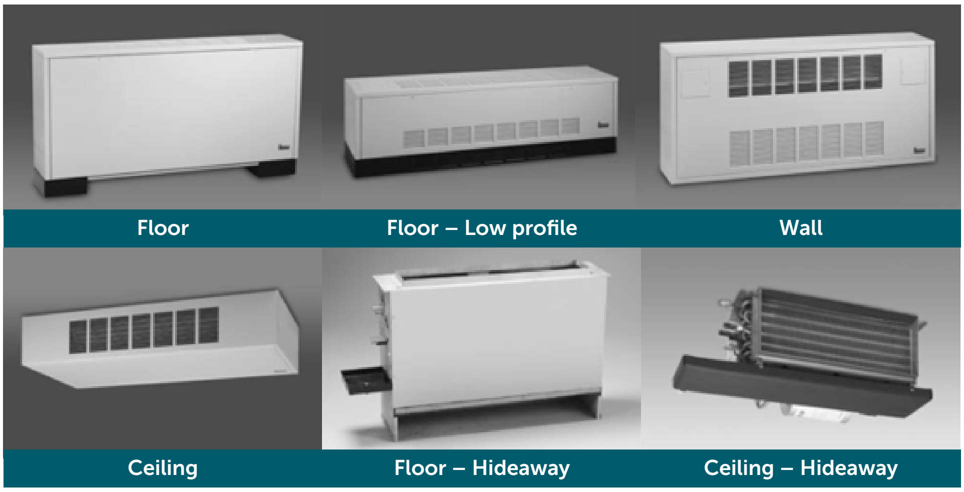


Figure 2.8 Fan coil units come in a variety of designs.
Source: Zehnder-Rittling

A fan coil unit is a small terminal unit that is often composed of only a blower and a heating and/or cooling coil, and is often used in hotels or apartments. Fan coils can draw outdoor air from local apertures but usually fresh air is provided by different means. There are many different types of fan coils as illustrated below, and they can be two-, three- or four-pipe units. A two-pipe unit is a single coil system with one inlet and one outlet pipe, providing heating and cooling, with seasonal changeover. Three-pipe units have two inlet pipes and a common return pipe, and two water coils. They can heat and cool simultaneously but the common return pipe always undermines energy efficiency. Four-pipe units are a better solution because they have two separate water coils with two inlet and two outlet pipes.

Ductless systems are packaged terminal units (or Variable Refrigerant Volume systems), which will be discussed later in this guide.

Natural convectors and baseboard heaters heat spaces quicker than radiators can. They are usually placed in entrance halls, foyers, kitchens, bathrooms, small halls or auditoria, and small workshops.

Hybrid systems mainly comprise chilled beams and underfloor air distribution systems.
Radiant and forced air systems can be combined and customized for different needs but can be more expensive. Usually, radiant systems heat and cool using a forced-air system, providing fresh air and taking over during cooling when condensation on the radiant systems is likely.

Chilled beams can be passive or active. Passive chilled beams don't have a fan, consisting only of a fin-and-tube heat exchanger contained in housing that is suspended from the ceiling. The cooling coil cools warm room air rising to the ceiling, causing it to descend back to the floor. Active chilled beams resemble induction units because they are connected to an integral primary air supply.

In underfloor air distribution (UFAD) systems, an underfloor plenum between the structural concrete slab and the underside of a raised access floor is used to deliver conditioned air directly into the occupied zone of a building. Air is most commonly delivered through floor level supply outlets. UFADs provide better thermal comfort and air quality and use less energy than traditional overhead systems. A system that combines heating, ventilation, air-conditioning, power and data cabling into one, easily accessible service plenum under a raised floor is flexible and cheaper than alternatives.

Heating and Cooling Equipment

Plant equipment produce thermal energy and deliver it to terminal units. Unlike other kinds of plant, 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.

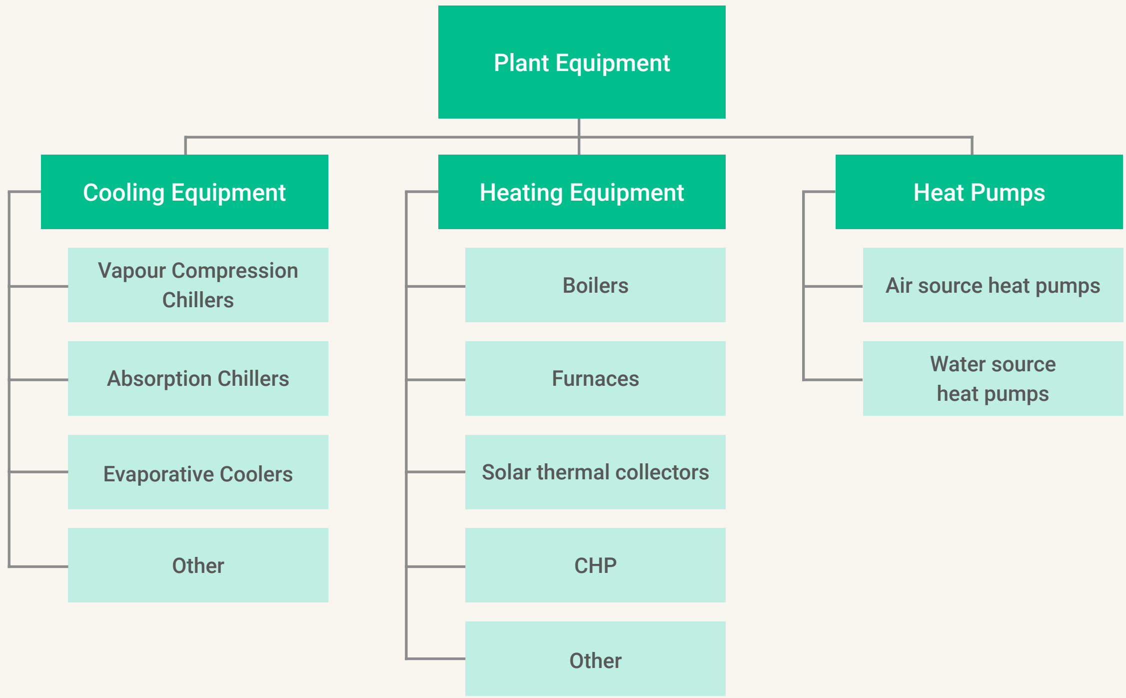


Figure 2.9 Different types of plant equipment.
Source: Mattheos Santamouris 2019

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 are characterized not by their efficiency, (they don't convert one form of energy to another) but by a measure called the coefficient of performance (COP), 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. COP is greater than 1.0 so for every electric kWh consumed in the compressor several thermal kWh are rejected from the building.

COP is highly dependent on the fluid temperatures that 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 a compression chiller is an absorption-based chiller which 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 150 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 configurations.

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.

Combined Heat and Power Plants

When it comes to heating, the main types of plant are boilers, furnaces, solar thermal collectors and combined heat and power systems (CHP). Boilers and furnaces use fossil fuel to heat air and water.

- Conventional boilers have a water temperature of between 80 and 90°C
- Low temperature boilers heat water at 35 to 40°C and are mainly used with floor heating systems
- Condensing boilers (usually gas or oil) are more efficient because they use extra heat from flue gas condensing in a secondary heat exchanger
- Co-generation of heat and power (CHP) is the simultaneous generation of heat and power from the same system. The system captures the heat energy from the electric generation
- Tri-generation is when some of the heat from a cogeneration plant is used to fuel a thermally-driven chiller.

The figure below compares a building served by a fossil-fuel powered grid and a conventional boiler, with a building served by a CHP unit for the same energy needs.

There are numerous CHP technologies including: reciprocating internal combustion engines (Otto cycle or diesel cycle); steam turbines (Rankine cycle); gas turbines (Brayton cycle); micro-turbines; Stirling engines (Stirling cycle) and fuel cells. Fuels cells are considered the most promising technologies because they do not produce greenhouse gases and they are becoming increasingly efficient.

Fuel cells use an electrochemical process that releases energy stored in natural gas or hydrogen fuel to create electricity. Heat is a by-product. Fuel cells that include a fuel reformer can use hydrogen from any hydrocarbon fuel. With a nearly one-to-one electricity-to-heat ratio, fuel cells are well suited for modern, low-energy buildings. There are four main types: molten carbonate fuel cells, solid oxide fuel cells, phosphoric acid fuel cells and polymer electrolyte membrane fuel cells.

Heat Pumps

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

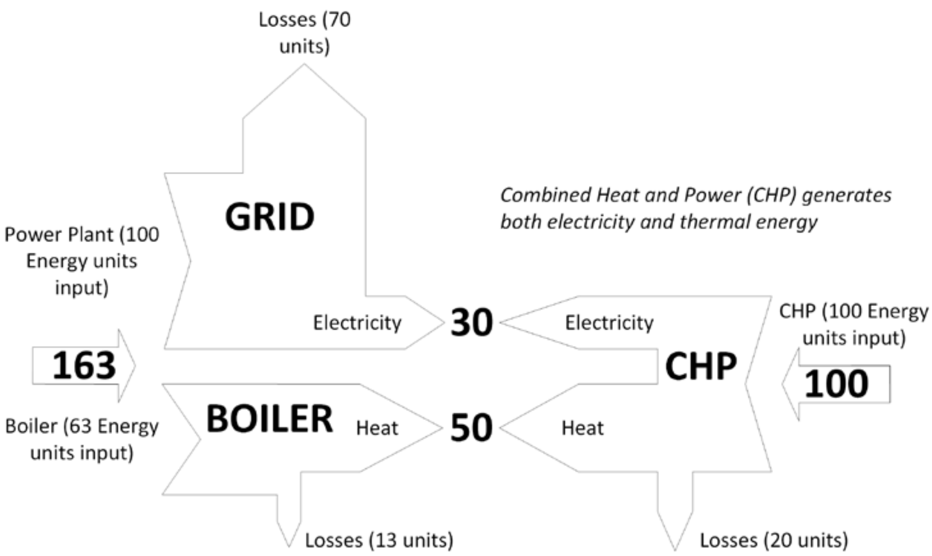


Figure 2.10 Comparison of a CHP system with conventional systems.
Source: Mattheos Santamouris 2019

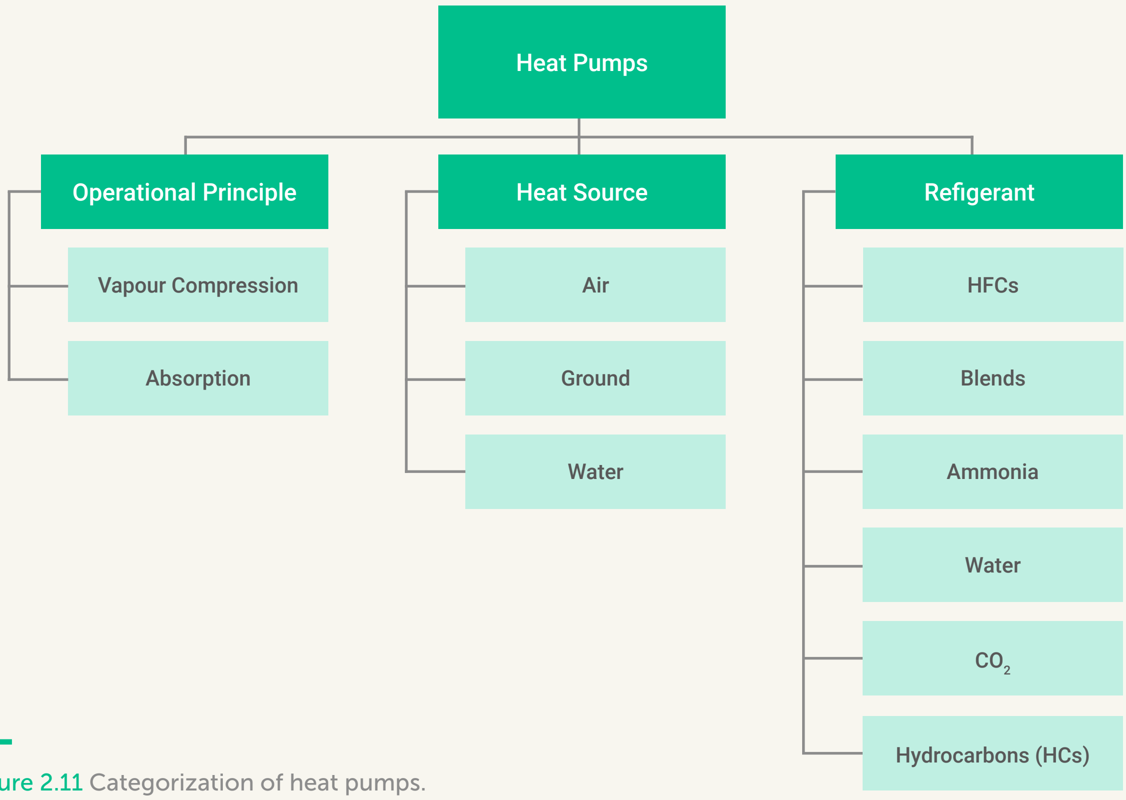


Figure 2.11 Categorization of heat pumps.
Source: Mattheos Santamouris 2019

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 are a very energy-efficient way to heat and cool spaces, 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, Hydrofluorocarbons (HFCs) are being phased out around the world because they are potent greenhouse gas, prompting research into safer replacement fluids.

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 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 duct work distributing the circulated air throughout the areas served.

Split-air conditioning systems are made up 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 pipe work and control cabling.

These days, most of these systems have an inverter that controls cooling and heating by varying the speed of the compressor and fans, making them quiet and cheap to operate.

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.

Variable Refrigerant Volume (VRV) or Variable Refrigerant Flow (VRF) systems are bigger, more complex versions of ductless multi-split systems. They have multiple compressors, many evaporators, and complex oil and refrigerant management and control systems. The term variable refrigerant flow refers to the system's ability to control the amount of refrigerant flowing to each of the evaporators, enabling the use of many evaporators of differing capacities and configurations, individualized comfort control, simultaneous heating and cooling in different zones, and heat recovery from one zone to another.

The systems are either two-pipe or three-pipe. The two-pipe inverter is similar to the multi-system, with several indoor units of different types and sizes. The indoor units are served by one or more outdoor condensing units, all using one common refrigerant pipe work system.

The three-pipe system has a similar configuration to the two-pipe system, with multiple indoor units connected to one or more outdoor units via one set of refrigeration pipe work. As its name suggests, it uses three separate pipes rather than two between all the units.

VRF systems provide many benefits and are considered one of the best options for heating and cooling in commercial buildings. They can serve many zones with individual set- point control.

Because VRF systems use variable speed compressors with wide capacity modulation capabilities, they can maintain precise temperature control. The VRF essentially eliminates duct losses, which are often estimated to be between 10 and 20% of total airflow in a ducted system.

VRF systems typically include two to three compressors, (one with variable speed), in each condensing unit, enabling wide capacity modulation. This yields high, part-load efficiency, which translates into high seasonal energy efficiency, because most of the time HVAC systems typically operate at 40 to 80% of maximum capacity.

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 back-up heater, a domestic hot water tank with internal electrical heater (optional) and a thermal energy emission system (floor heating and cooling, fan coils, radiators).

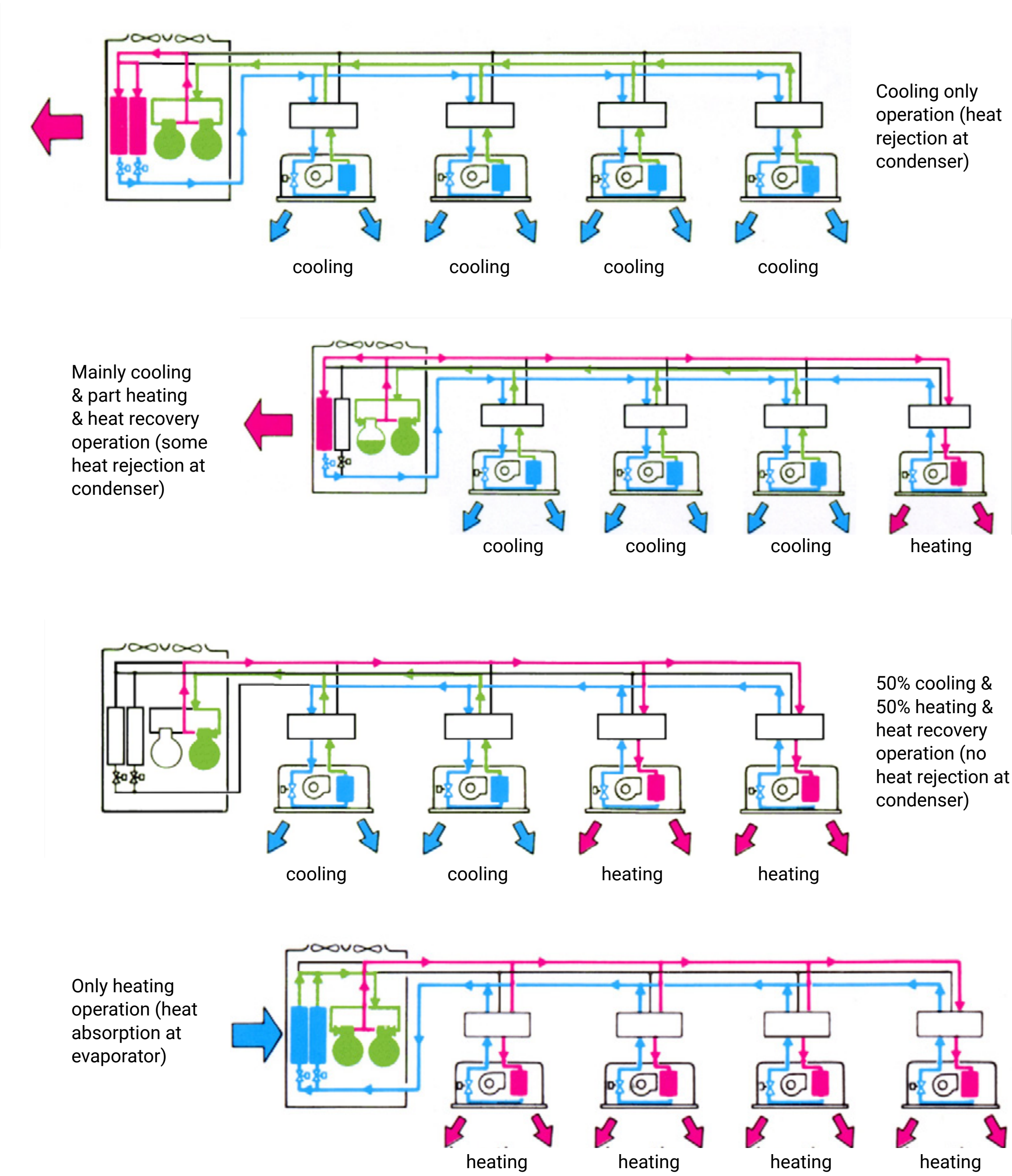


Figure 2.12 Different modes of operation of VRV/VRF systems.
Source: DAIKIN

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

Water source heat pumps (WSHP) are either distributed systems where small, unitary water-source heat pumps are located throughout a building, or central systems consisting of one or more heat pumps coupled with a condenser loop. In a central system, the heat pumps are located in a single mechanical equipment room, providing fluid to hydronic heating and cooling terminal units throughout the building.

Lighting and Plug Loads

In recent years, new technology and more stringent lighting standards have cut the amount of electricity used in commercial buildings.

However, lighting in commercial buildings still uses large amounts of electricity, accounting for 15 to 20% of all electricity consumed, compared with between 25 and 30%, 20 years ago.

A high-efficiency lighting system uses both natural and artificial lighting to provide a comfortable environment and to cut energy costs. It is made up of high-efficiency lamps, ballasts and luminaires, with, at best, a limited number of fixture and lamp types. A mix of natural and artificial lighting, good architectural design, and a smart lighting control system can maximize light and minimise energy consumption.

High-Efficiency Lamps

When choosing a lamp, efficacy (lumens per watt), colour temperature, colour rendering index, life and lumen maintenance, availability, switching, dimming capability, and cost, should be considered. State of the art lighting types include standard fluorescent lamps, compact fluorescent lamps, high-intensity discharge lamps, halogen lamps, and light-emitting diode.

Fluorescent and compact fluorescent lamps work well in contemporary commercial buildings. They are energy efficient, have great colour-rendering properties, last a long time, are easy to control, and inexpensive.

Halogen lamps are a category of incandescent bulb that offer high-quality light and energy efficiency. High-intensity discharge lamps produce very bright light, making them useful for lighting large areas. They are often used in high-ceiling spaces with open layouts such as sports arenas, storage areas and big-box retail stores.

LEDs are highly efficient and durable, producing directional lighting, and come close to providing the quality of light produced by incandescent bulbs.

Typical efficacies, lifetimes, and colour quality of lamps[1]

	Efficacy (lumens/ Watt)	Typical rated lifetime (hours)	Colour rendering index[2]
Standard fluorescent			
– Fluorescent T5	25 – 55	6,000 - 7,500	52 - 75
– Fluorescent T8	35 – 87	7,500 - 20,000	52 - 90
– Fluorescent T12	35 – 92	7,500 - 20,000	50 - 92
Compact fluorescent	40 – 70	10,000	82
Incandescent	10-19	750 - 2,500	97
High-intensity discharge			
– Mercury vapour	25 – 50	29,000	15 - 50
– Metal halide	50 – 115	3,000 - 20,000	65 - 70
– High-pressure sodium	50 – 124	29,000	22
Halogen	14 – 20	2,000 - 3,500	99
LED	20 – 100	15,000 - 50,000	33-97

[1] Efficacy is a measure of how well a light source turns input power into the desired output, which is lumens. Theoretical maximum luminous efficacy of white light is 220 lumens/Watt.
[2] Colour Rendering Index (CRI) indicates a lamp's ability to show natural colours. The highest possible CRI value is 100, which would be equivalent to daylight.

High-Efficiency Ballasts

Ballasts are important both in terms of efficiency and lighting quality. Modern electronic ballasts operate at a frequency above 20 kHz, allowing the lamps to operate more efficiently, providing 10 to 15% more light, and eliminating the 60-cycle hum and visible flicker normally associated with electromagnetic ballasts. Ballasts extend the life of a lamp and improve colour characteristics. Thanks to modern, solid-state circuitry they are practical, reliable and cool-running.

Light output ratings published by lamp manufacturers are based on powering the lamp with a "reference ballast" as specified by SAI or ANSI standards. Electronic ballasts have several different ballast

Types of luminaires with respect to application.

Rescent Luminaire	Description	Benefits	Cautions	Applications
Indirect/Direct Linear Luminaire	Primarily indirect, pendant or wall mounted, T8, T5 or T5HO lamping	Soft, even illumination, good visual comfort, easily dimmed	Choose spacing for good ceiling brightness uniformity	High and low bay areas and classrooms
Indirect/Direct Decorative Luminaire	Typically compact fluorescent or induction lamping	Significant energy savings, performance comparable to incandescent	Select diffuser for good brightness uniformity on glowing elements	Small offices, lobbies, waiting areas, atriums, and corridors
Linear Strip Luminaire	Surface mounted or pendant mounted with or without side reflectors, typically T8 lamping	Energy-efficient, small size, low-cost, easily dimmed	Best when concealed	In coves or wall slots, on top of cabinets, stacks or lockers, and mechanical rooms
Task Luminaire	Linear wall mounted "under shelf" or "arm type"	Task lighting allows for lower ambient lighting levels	Provide appropriate task/ambient contrast ratios	Any task surface (desks, counters, workbenches, etc.)
Indirect Recessed Luminaire	Recessed (light is directed up toward top of housing and reflected back down), typically 2' x 2' or 2' x 4', T8 or CFL biax lamping	Optimised for fewer lamps than typical recessed lensed troffer luminaires, good visual comfort	Does not brighten ceiling, consider minor supplemental lighting (such as wall sconces)	Corridors, open/private offices (can replace standard troffer in many applications)

Source: Energy Efficient Lighting, D. Nelson and Associates, WBDG, 2016

factors. A lighting system designer can adjust the lighting level to meet the requirements of a particular application, trading watts for lumens by selecting the appropriate ballast.

The most widespread electronic ballasts are instant-start that use 1.5 to 2 watts less energy per lamp than the rapid-start alternative. They start lamps without delay or flashing, providing high-quality lighting. However, they have a short life expectancy of 10-15,000 starts.

Rapid start ballasts are less efficient but they have a longer life expectancy of up to 20,000 starts, and are cheaper.

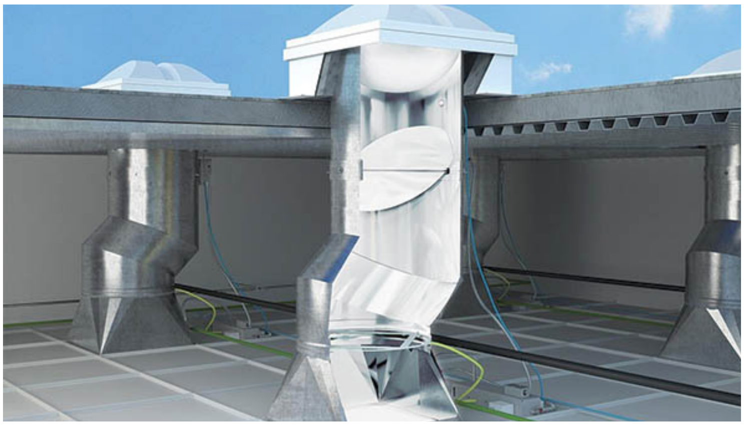
Program Rapid-Start electronic ballasts have been designed for use with occupancy sensors and have a life expectancy of up to 30,000 lamp starts.

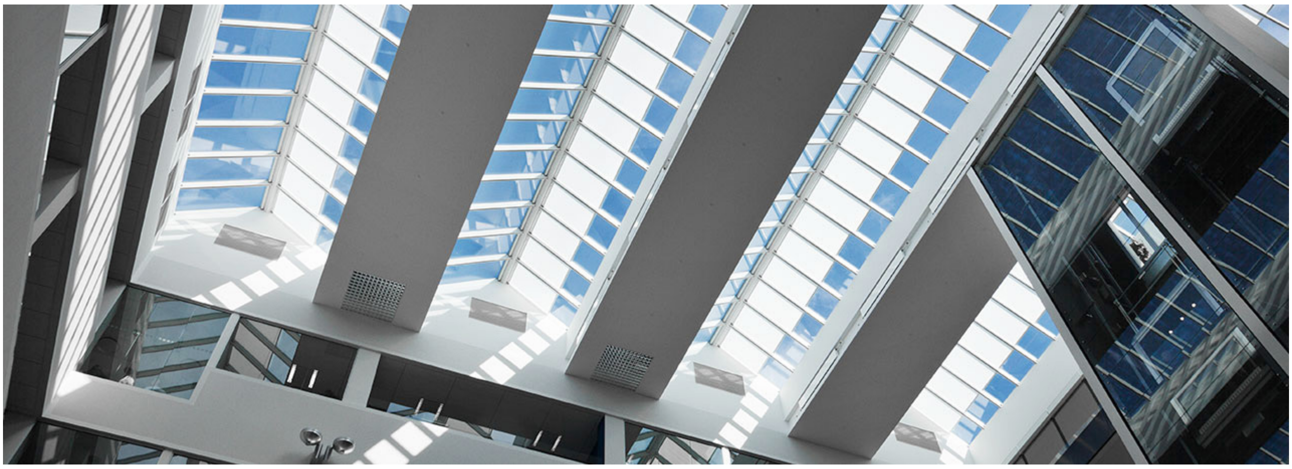
Programmed-Start electronic ballasts ensure the longest lamp life in frequent starting conditions, with a life expectancy of up to 50,000 starts, making them suitable for intermittent operation.

Luminaires

An efficient luminaire optimizes the system performance of each of its components. Choosing the right type of light fixture, or luminaire, is important to achieve high-quality, efficient lighting. A luminaire consists of lamps, lamp sockets, ballasts, reflective material, and shields. Some types can help conserve energy and make the best use of a lighting system by providing the most appropriate direction, distribution and diffusion of light.

As the luminaires are the most visible part of any lighting system, their construction, design and appearance are important parameters, along with cost.





Natural Lighting Enhancement Systems

Natural lighting is free and can provide a comfortable indoor environment but it isn't always easy to access in commercial buildings. However, using the following technologies, sunlight can reach deeper into rooms, take advantage of daylight even on cloudy days, control direct sunlight in sunny climates, and transfer daylight to windowless spaces.

- **Clerestory windows**: placed above eye level, they allow light to enter a building without glare
- **Hollow structured light tubes**: using a reflective lining, they contain light and transfer it to a windowless space
- **Skylights**: provide daylight and ventilation
- **Transparent solid light tubes**: contain light by total internal reflection and distribute it over their entire length

Clockwise from top left: Clerestory windows, reflective light tubes, transparent solid tubes and skylights. Photos: WRNS, Commercial Architecture, Krapf AG, VELUX Studio.

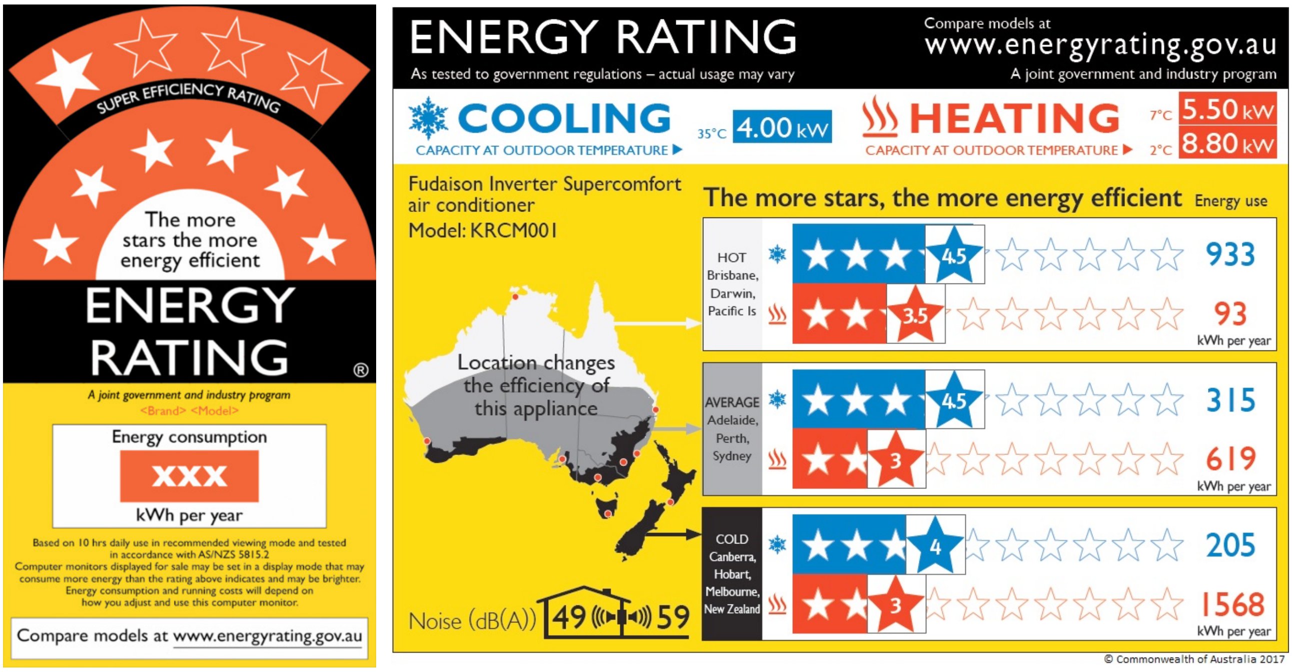


Figure 2.13 Energy rating labels for a computer (left) and a room air-conditioner (right).

Plug Loads

A significant amount of the total energy consumed by commercial buildings comes from so-called plug load energy, that is, energy used by things such as office equipment and computers. They can also affect heating and cooling loads but overall, plug loads have a negative effect in commercial buildings because they increase energy consumption.

Strategic planning and careful analysis of these sources and their interactions with HVAC systems can cut energy use in a building.

The Equipment Energy Efficiency (E3) program in Australia and New Zealand is a unified, integrated energy efficiency standards and energy labelling program for equipment and appliances. In 2012, the introduction of the Greenhouse and Energy Minimum Standards (GEMS) Act created a national framework for product energy efficiency in Australia.
E3 and GEMS stipulate that most black and white appliances and other pieces of equipment, including computers, data centres, lighting, electric motors and air-conditioners, have to be certified and labelled.

Building Automation and Controls

Building automation and control (BAC) and Technical Building Management (TBM) systems act as command centres in buildings.

It is here that information for all of a building's technology is integrated, and it is from here that heating and cooling systems, ventilation and air-conditioning plants, lighting, and sun- and fire-protection systems are controlled, making them a key part of any drive for energy efficiency. Access to and security for a building are also controlled from here.

Standards and Guidelines

In 2018, Australia adopted the ISO/IEC14543-3 standard, which specifies a wireless protocol for low-powered devices, in homes and offices. The protocol is designed to keep energy consumption by sensors and switches very low, and it is the backbone of Konnex (KNX), an open standard for commercial and residential building automation that manages HVAC systems, lighting, blinds and shutters and security systems, implements energy management, and manages black and white appliances.

The Wireless Session Protocol (WSP) system consists of two or three components: a transmitter, a receiver and a repeater. The standard enables the integration of all KNX-badged building and equipment systems, which means, in practice, the products of all major producers in Australia and New Zealand. This has created a new market for systems producers and integrators, facility managers, and residential and commercial building owners.

Class	Energy efficiency
A	**Corresponds to high energy performance BACS and TBM** • Networked room automation with automatic demand control • Scheduled maintenance • Energy monitoring • Sustainable energy optimisation
B	**Corresponds to advanced BACS and some specific TBM functions** • Networked room automation with automatic demand control • Energy monitoring
C	**Corresponds to standard BACS** • Networked building automation of primary plants • No electronic room automation, thermostatic valves for radiators • No energy monitoring
D	**Corresponds to non energy efficient BACS** Building with such systems shall be retrofitted. New buildings shall not be built with such systems. • Without networked building automation functions • No electronic room automation • No energy monitoring

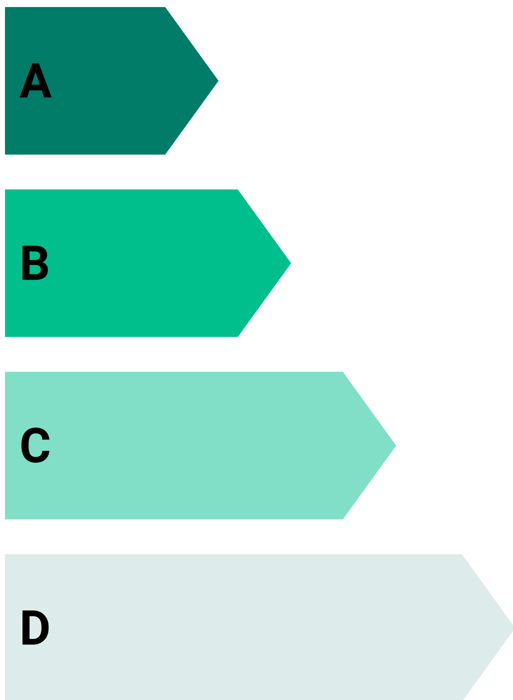


Figure 2.14 BAC systems classes with respect to energy efficiency.
Source: Siemens

BAC efficiency factors for thermal energy in non-residential buildings.

Non-residential building types	BAC efficiency factors thermal			
	D	C	B	A
	Non energy efficient	Standard (Reference)	Advanced energy efficiency	High energy efficiency
Offices	1.51	1	0.80	0.70
Lecture halls	1.24	1	0.75	0.5[a]
Educational buildings (schools)	1.20	1	0.88	0.80
Hospitals	1.31	1	0.91	0.86
Hotels	1.31	1	0.85	0.68
Restaurants	1.23	1	0.77	0.68
Wholesale and retail buildings	1.56	1	0.73	0.6[a]
Other types: • Sport facilities • Storage • Industrial facilities • etc		1		

[a] The values are highly dependent on heating/cooling demand for ventilation

BAC efficiency factors for electrical energy in non-residential buildings.

Non-residential building types	BAC efficiency factors electrical			
	D	C	B	A
	Non energy efficient	Standard (Reference)	Advanced energy efficiency	High energy efficiency
Offices	1.10	1	0.93	0.87
Lecture halls	1.06	1	0.94	0.89
Educational buildings (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 buildings	1.08	1	0.95	0.91
Other types: • Sport facilities • Storage • Industrial facilities • etc		1		

Source: Siemens

The aforementioned standard is particularly important because it is the most widely adopted standard, linking BAC systems to a building's energy efficiency by defining four different efficiency classes (A, B, C, D), as seen below.

The impact of a BAC class on a building's energy efficiency varies across building types and operational patterns. Efficiency factors for thermal energy and electricity in different types of buildings are listed below. Class C is the standard base case for BAC and TBM systems.

Upgrading an old, inefficient Class D BAC system in a wholesale and retail building with a new and highly efficient Class A system, without any other retrofit measures, will reduce thermal energy requirements by 60% and electrical energy requirements by 15.7%. The huge reduction in thermal energy requirements is due to the BAC's ability to control the HVAC systems, compared with the very basic controls in outdated systems.

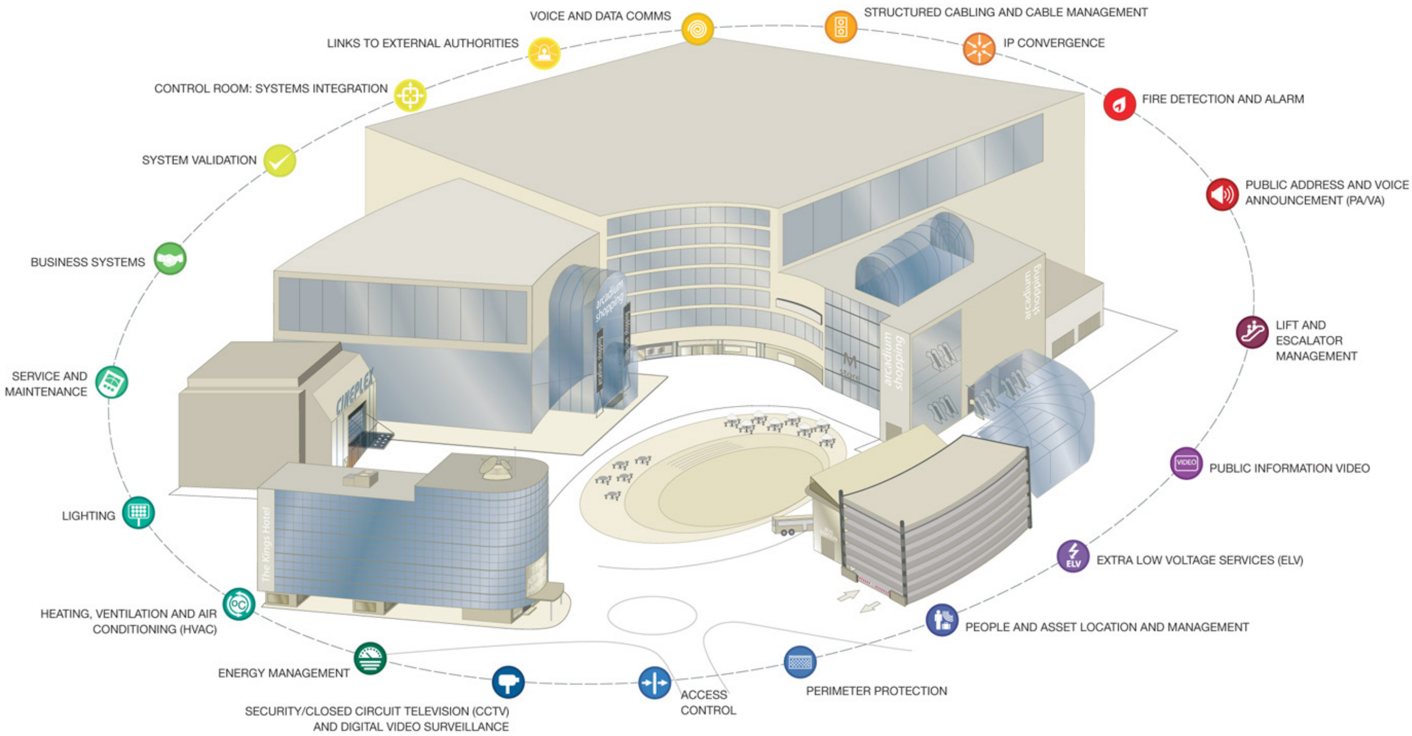


Figure 2.15 Integrated Building Automation and Controls.
Source: Honeywell

Building Automation and Controls, Building Management Systems and energy efficiency

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 efficiency. They control:

- Heating, ventilation and air conditioning
- Lighting
- Smoke detection and fire alarms
- Motion detectors, CCTV, security and access control
- Information and Communications Technology systems
- Lifts
- Industrial processes and equipment
- Shading devices
- Smart meters

They may also be used to monitor and control power distribution, energy consumption and uninterrupted power supplies. Together, those parameters create an integrated and effectively operated building, as shown below.

The phrases 'Building Energy Management Systems' and 'Building Management Systems' are being gradually replaced with 'Building Automation and Control' and 'Technical Building Management' systems. But whichever term you use, these systems help managers get the most out of buildings. Alarms and alerts notify a manager when parameters are exceeded, or when failures have or will occur. Data collection allows managers to compare the performance of different spaces and buildings and to set benchmarks for performance. Finally, they provide all the data needed for energy and environmental audits.

But even the best BAC and TBM system depends on the efficiency of the building's various systems, such as its HVAC. A BAC system's efficacy also depends on the range and quality of the information it receives from sensors, and on how this information is used. In that sense, even a state-of-the-art BAC system needs to be properly commissioned and regularly fine tuned.

End Notes

1. 2011 Buildings Energy Data Book, Table 5.6.9, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy (https://catalog.data.gov/dataset/buildings-energy-data-book-6d4d2)

Energy-efficient lighting was installed throughout Piccadilly Tower.
Photo: Stockland

Piccadilly Tower (Sydney)

Stockland is a leading property group and a top-50 ASX-listed company committed to reducing its ecological footprint. In 2006, its Sydney head office joined Australia's flagship sustainability program for businesses, CitySwitch, to adopt a sustainable approach to manage and operate its building stock and cut energy and water consumption.

Snapshot

Year built 1980s

Location Piccadilly Tower, 133-145 Castlereagh St, Sydney, NSW

Size (NLA) 10,151m^2

Tenancy 32 storeys, 274 parking spaces

Refurbishment 2006 – 2009

Project costs $123.2M (including building acquisition)

NABERS Energy Initial: 2.5, Target: 5.0

Green Star rating 6 Star

Key features
- Tri-generation gas turbine for electricity
- Committee to help change staff behaviour
- T5 fluorescent lighting
- Sub-metering systems
- Motion sensors for lighting
- Energy-intensive CRT monitors replaced flat-screen LCDs
- Energy efficient appliances

Energy saving 38% cut in energy consumption

Greenhouse saving 49% less CO_2 emissions

Annual saving $90,000/p.a.

Stockland transformed an outdated office tower into a contemporary, sustainable workplace. Photo: Stockland

A year later, the company moved its Sydney office to Piccadilly Tower, which was built in the 1980s. The developer wanted to refurbish the building to meet the highest environmental standards possible.

Objectives:

- Create office space that maximized employees' productivity; set new standards in office refurbishment
- Achieve a 5.0 Star NABERS Energy rating

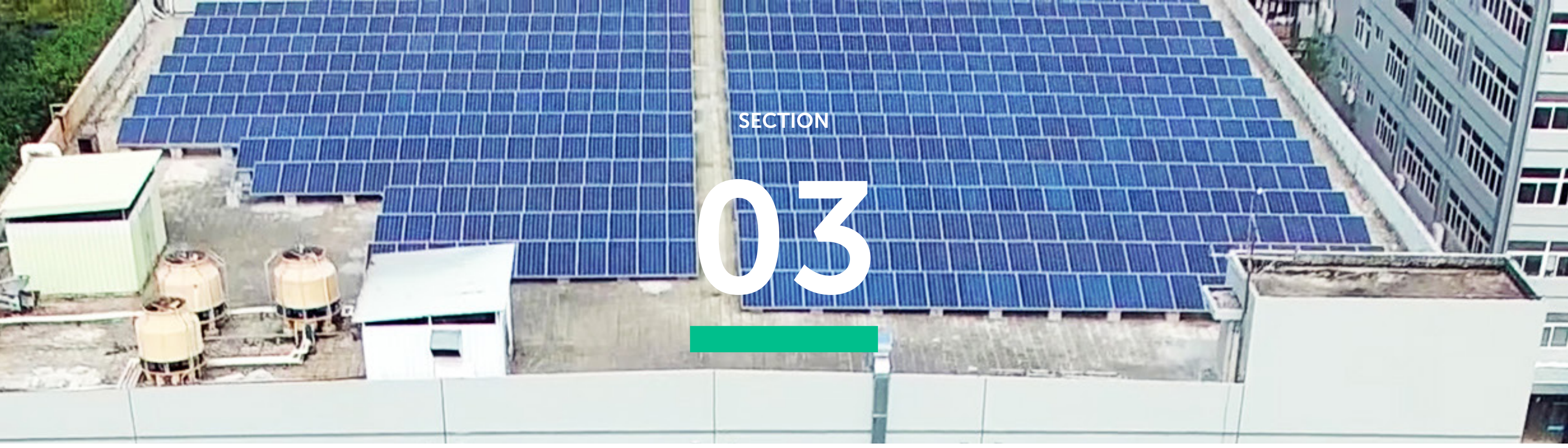
Features and Implementation:

- Sub-metering for monitoring energy use and more efficient building operation
- Tri-generation system for 70% of tenancy's energy demand. Electricity produced using an onsite gas turbine
- Occupancy motion sensors to control office lighting between 7pm and 8am, and round-the-clock in meeting rooms
- Printers reduced from about 140 to 40
- Energy efficient T5 fluorescent lamps installed through building
- Energy efficient appliances provided in kitchen and photocopying areas
- Timed air-conditioning system installed in meeting rooms
- CRT monitors replaced with flat screen LCDs
- Committee formed to educate and encourage behavioural change among employees before they moved into Piccadilly Tower

Outcomes:

- 5 Star NABERS Energy rating achieved without GreenPower
- Energy consumption cut by 38%; CO_2 emissions by 49%
- Peripheral energy consumption cut out-of-hours
- More than 80% of employees joined the company's sustainability drive

Read more at: cityswitch.net.au

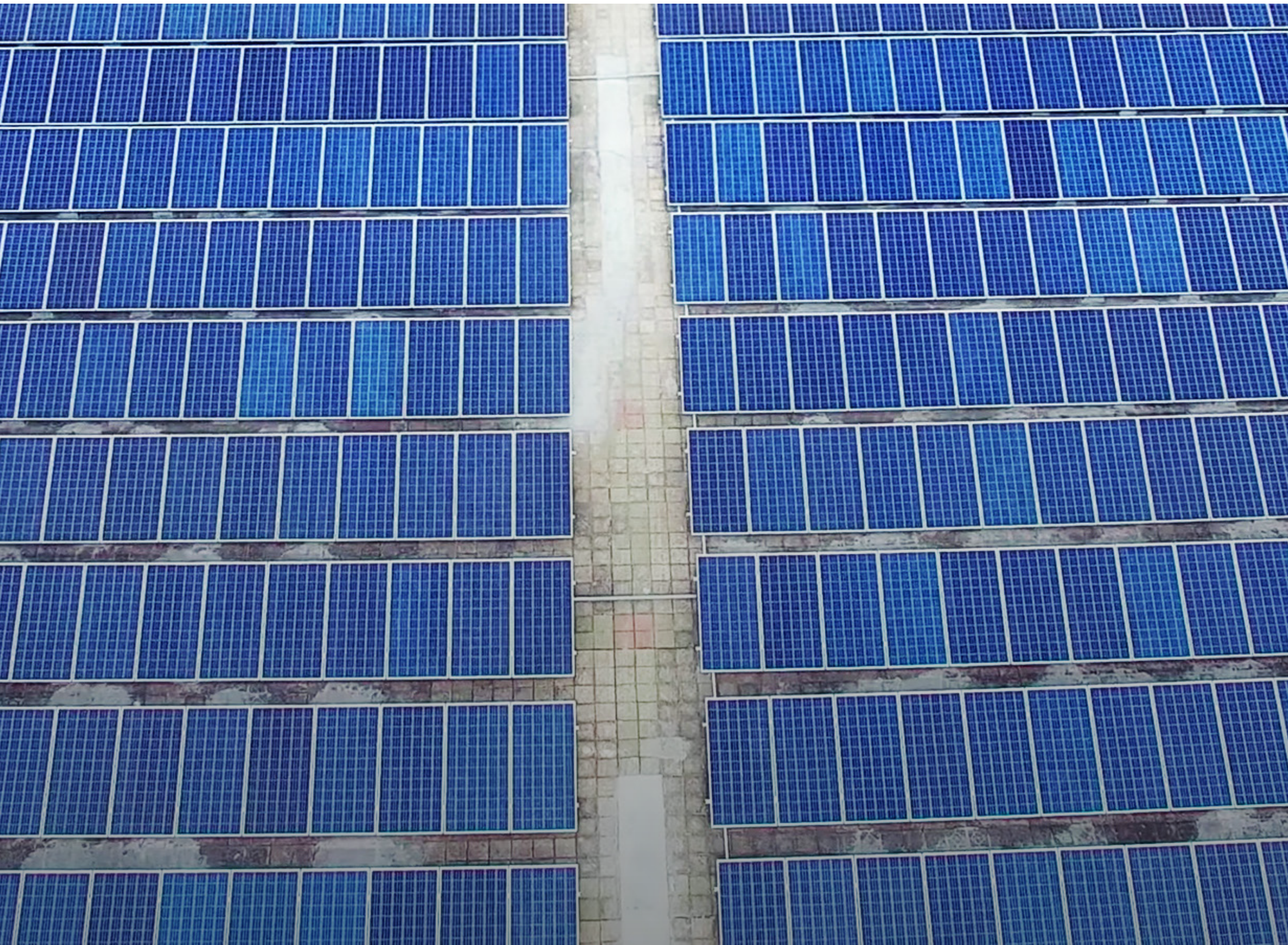


SECTION

03

Renewable Energy Sources

Local energy generation through photovoltaics, solar thermal or wind can ensure more ‘green’ electrons are being used to supply a buildings requirements, hence reducing its environmental impact.



Solar Thermal Systems

Solar energy can be converted into useful thermal or electrical energy for the residential, commercial and industrial sector. It is essentially converted by a solar thermal collector.

There are two types of solar thermal collectors: those with and those without a sun-tracking mechanism. Solar thermal collectors, where all parts of the collector system are stationary, are usually used for low to medium temperature applications. Commercially available types include:

- Uncovered collectors without casing and insulation
- Flat plate collectors with a selective or non-selective absorber
- Vacuum tube collectors, direct flow or heat pipe
- Compound parabolic concentrator collectors

Solar thermal collectors with solar radiation concentration are used for medium- and high-temperature applications. Solar concentration is the re-direction of solar radiation to enhance the irradiance received by the absorber or the receiver. Concentrating solar thermal systems use mirrors or lenses with tracking systems to focus a large area of sunlight onto a smaller area.

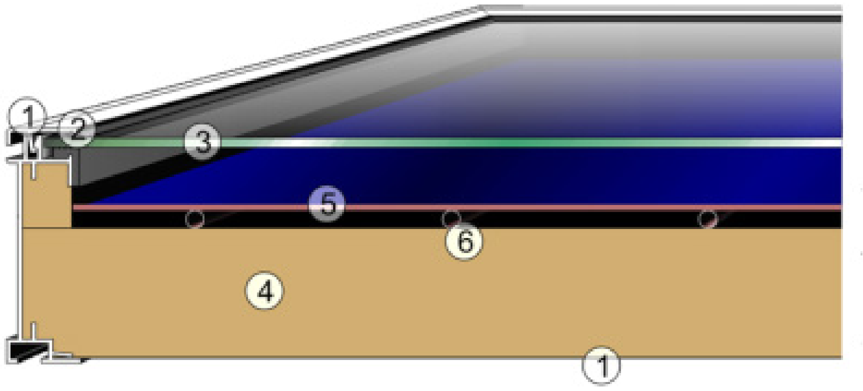
There are four concentrating solar thermal commercial technologies available in the market: linear Fresnel collectors, parabolic trough collectors, solar towers, and the parabolic dish (mainly used for steam production for industrial applications and electricity production).

Solar thermal systems may produce fluid of low (T < 100°C), medium (100°< T < 400°C) or high (T > 400°C)

Figure 3.1 Types of solar thermal collectors.
Sources: floridasolardesigngroup.com; CRES; Solair; Calpak

Figure 3.2 Schematic of a flat plate solar collector with liquid transport medium. Source: Solarpraxis, 2005

1 Casing
2 Seal
3 Transparent Cover
4 Thermal Insulant
5 Absorber Plate
6 Tube



temperatures which can be used directly, or which can be transformed into other forms of mechanical, electrical and chemical energy. In commercial buildings, they can be used to produce sanitary hot water, hot air for space heating and hot water for space heating and/or cooling.

The more complex a system, the higher the temperature needed. The simplest type of system is the thermosiphon system for sanitary hot water, mainly used for residential applications and in small hotels and hostels.

Forced-circulation systems use a pump or a fan to circulate the heat transfer fluid through the collectors. They have sophisticated control systems and the storage tank can be placed independent of the collector, and they are appropriate for more complex systems and higher consumption. They have lower thermal losses and are ideal for commercial buildings.

Solar Thermal Collectors

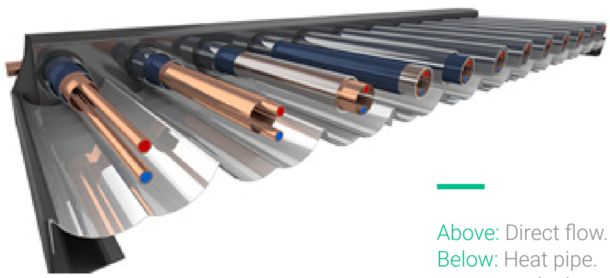
Simple and reliable, flat plate collectors are widely used to produce domestic hot water. They collect both beam and diffuse radiation, have no moving parts or tracking equipment, and are easy to install and maintain.

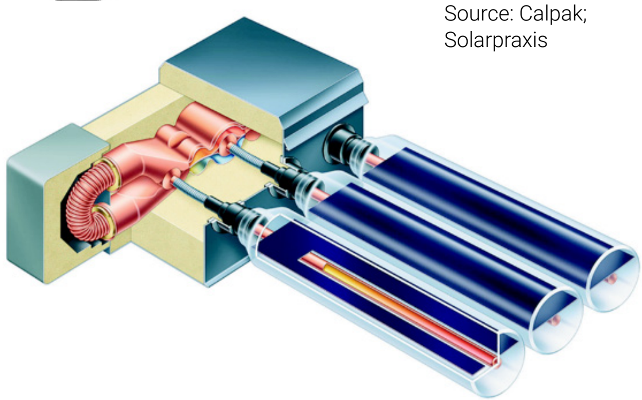
They are installed facing the equator, and the optimal tilt for the collector plate should be close to the latitude of the location (+/-15°). For year-round hot water application, the optimum angle is Latitude + 5°.

The main components of a typical flat plate collector are depicted below. The flat plate collectors reach maximum efficiency in a range of 30 to 80°C. Thanks to the introduction of selective coatings, the heat transfer stagnation temperature can reach as high as 200°C.

Vacuum tube collectors consist of a series of vacuum glass tubes connected to a common manifold, each of which has an absorber fin attached to a copper pipe. The fin is covered with a selective coating that transfers heat to the fluid that circulates through the copper pipe. Vacuum tube collectors have less thermal losses than a flat plate, resulting in operating temperatures higher than 100°C.

The most common types of vacuum tube collectors are shown here:





Above: Direct flow.
Below: Heat pipe.
Source: Calpak; Solarpraxis

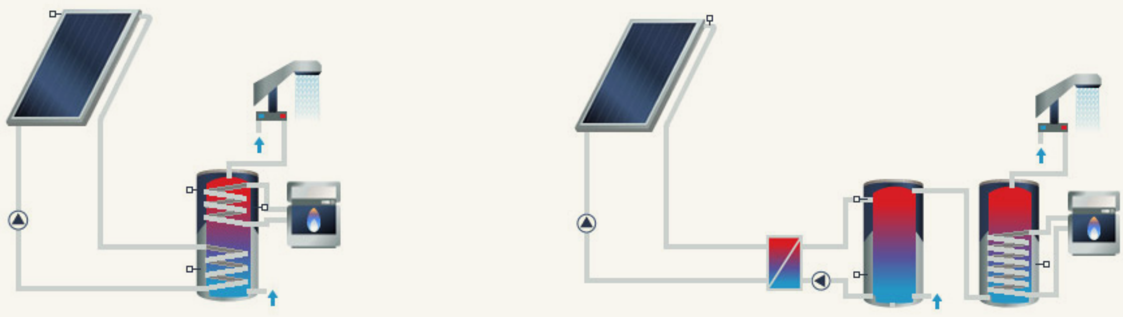


Figure 3.3 Forced-Circulation solar thermal systems configurations with, left, internal heat exchanger and, right, external heat exchanger and two storage tanks. Source: Valentin Software

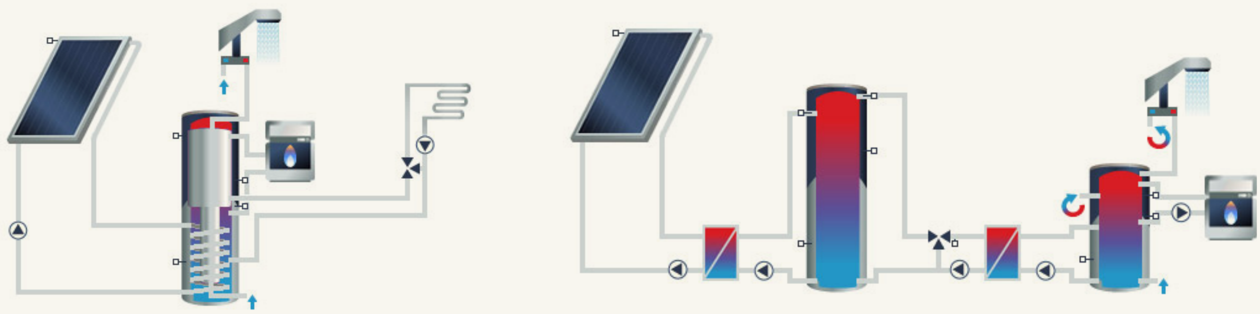


Figure 3.4 Solar combi system configurations with tank-in-tank storage and separate storage tanks for hot water and heating. Source: Valentin Software

Direct flow evacuated tube collectors, or U-pipe collectors, have two copper pipes inside a vacuum glass tube. One pipe is the flow while the other is the return. Both are connected at the bottom of the tube with a U-bend. The absorber fin separates the flow and the return pipes. If a tube cracks, the whole system must be drained.

In a heat pipe, the vacuum glass tube contains the absorber fin and one copper pipe in which the heat transfer fluid flows. The vacuum helps heat the fluid quickly so that it rises to the top of the pipe. The main advantage of heat pipe collectors is that there is a “dry” connection between the absorber plate and the manifold, making installation much easier. If a tube cracks, each individual tube can be exchanged without emptying the entire system or dismantling the collector.

Flat plate solar thermal collectors may be connected in a series, in parallel or using a combination of the two connection modes. When the collectors are connected in series, higher outcome temperatures are reached but the plant is less efficient and the pressure losses are higher than with parallel connection.

Solar Thermal Storage

Storage tanks maintain a balance between a solar thermal system’s heat production and its heat consumption by temporarily storing excess heat. Most solar heating systems provide storage of a few hours’ to a day's worth of energy. The most commonly used are thermally insulated tanks with a heat exchanger.

Tanks are classified according to three criteria:

- Horizontal or vertical position

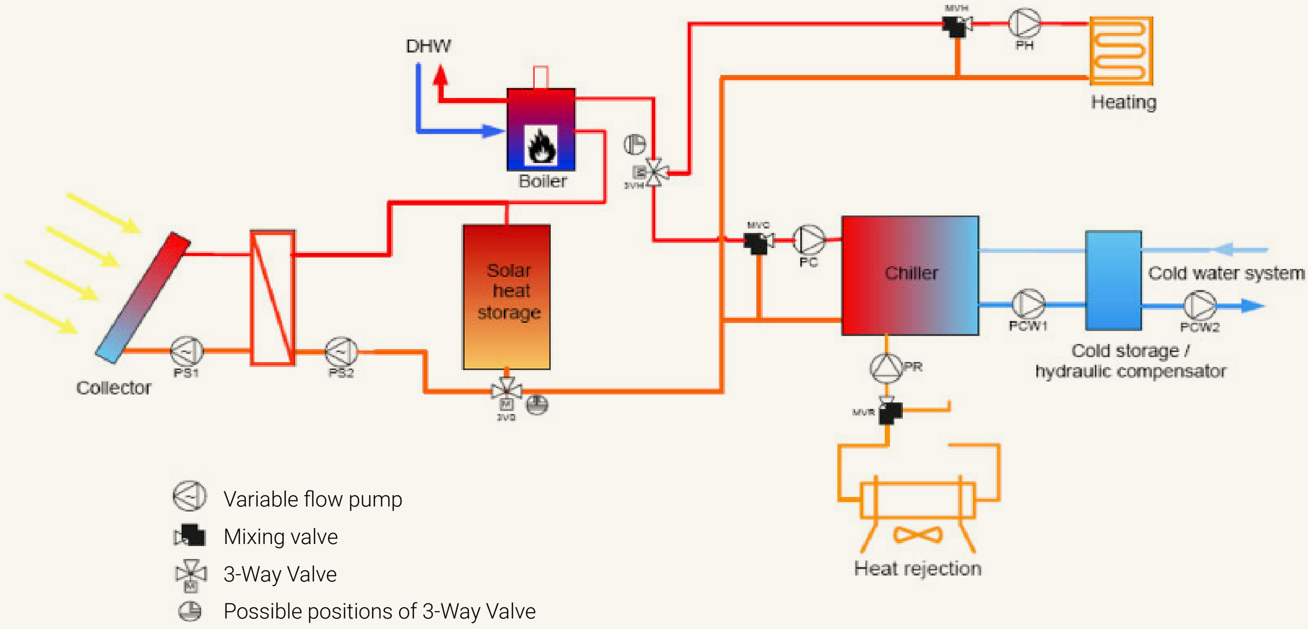


Figure 3.5 A “closed circuit” solar cooling system.
Source: Henning

- With or without heat exchanger. If a heat exchanger is included, is it a serpentine or shell and tube type
- They are made of copper, stainless steel or plastic

Storage media include water, phase-change materials or other means depending on the size and application. For commercial building applications, storage tanks can range in size from a few hundred to some thousands of litres.

Solar Thermal Applications

Around the world, the predominant solar thermal system is the thermosiphon system, which is used to produce sanitary hot water in the domestic sector. Storage capacity should be 1.5 times daily demand. There are rules of thumb considering the "storage volume /collector area" ratio (e.g. 75 l of storage volume for 1m^2 of solar collector); they provide a first approximation of the storage vessel.

When sizing a solar system, you must not assume solar energy is available all year round. You must also take into account the fact that buildings are not always used at full capacity.

Usually thermosiphon systems can cover all of a building’s hot water requirements in summer, and between 40 and 80% over the year. The ratio of useful solar heat to back-up heat, plus electrical energy for pumps and controls is known as solar energy factor.

Small, custom-built systems are forced-circulation modular solar heating systems with remote storage, used for hot water preparation and /or space heating and/or cooling. They have well-identified configurations, and are assembled from components chosen by the manufacturer, or by the consulting engineer who produced the technical documentation and purchased the components from suppliers.

In general, the assortment file includes possible system configurations, the assortment of components, and their possible combinations and dimensions.

The collector area is usually greater than 1m^2 and less than 3m^3 and store volume is less than 3m^3.

Large custom-built systems are forced-circulation solar heating systems used to produce hot water and/ or space heating/cooling for a specific situation by combining various components to create a unique system. In general, the collector area is greater than 3m² and the store volume is greater than 3m³.

A solar heating system that provides both hot water and space heating is a “combi” system. Domestic hot water and heating water are in separate tanks. A tank-in-tank configuration or separate tanks should be considered when designing a combi system.

One application of great interest to solar thermal energy is air-conditioning using absorption or adsorption thermal chillers. The cooling load is generally coincident with the availability of solar energy and so the cooling requirements of a building coincide with high solar radiation.

Solar cooling systems use non-toxic fluids, such as water or salt solutions. They can be used either as stand-alone systems or in combination with conventional cooling systems, to meet the cooling requirements of all types of buildings.

Solar cooling helps prevent overheating during summer and helps to reduce electrical peak loads. There are “closed systems”, which have solar chillers providing cold water for the air conditioning; and “open systems”, based on an evaporative cooling and dehumidification technology known as desiccant evaporative cooling. Around the world, closed systems are more common in the commercial sector.

Case study

A solar heating and cooling system installed in an office building in the town of Pikermi, in south-eastern Greece is an interesting case study for solar thermal collectors. The building has an air-conditioned area of 427m², with 1296m³ volume, which is typical for medium-sized offices and multi-family buildings. Water heated to 40°C is used by fan coil units for covering part of the building’s thermal load. When demand is low, part of thermal energy produced by the solar collector's plant is stored in an underground thermal energy unit. In cooling mode, the absorption machine is driven by water heated to between 65 and 80°C by the solar collectors, providing chilled water for cooling at between 12 and 15°C. The heat pump, which serves as auxiliary system, is driven by solar energy.

Solar thermal collectors on top of an office building in Greece.

A mean yearly solar fraction of approximately 85% of the total thermal and cooling building needs is achieved. The plant has operated without any major problems since December 2011.

Solar heating and cooling technical characteristics for the Pikermi office

Solar thermal collectors	Selective flat plate, 150 m² gross area
Heating load	12.3 MWh/y
Cooling load	19.4 MWh/y
Solar cooling	35 kW closed cycle – absorption (LiBr-H2O)
Heat storage	58 m3 water
Heat Hump	18 kW water to water, driven by solar heat

Photovoltaics

An example of Building Integrated Photovoltaics (BIPV)

PVs are gaining momentum in building applications because of new building energy regulations (in some cases, making PVs compulsory on roofs), and because of the declining cost of PV modules.

The levelised cost of PV-generated electricity installed in commercial and industrial buildings is now on par if not below most fossil-fuel powered generation stations.

There are four broad PV types. The most common is the crystalline silicon (c-Si) module, which makes up between 85 and 90% of the global market. That market can be broken into single crystalline (sc-Si) and multi-crystalline (mc-Si) cells.

Thin films account for another 10 to 15% of the market. There are different types of thin films including amorphous (a-Si) and micromorph silicon (a-Si/μc-Si), Cadmium-Telluride (CdTe), Copper-Indium-Diselenide (CIS) and Copper-Indium-Gallium-Diselenide (CIGS).

There is a small market for emerging technologies such as advanced thin films, and organic and Perovskite cells. Finally, there are concentrator technologies (CPV), which use an optical concentrator system that focuses solar radiation onto a small, high-efficiency cell. The last two categories are not yet commercially available.

When it comes to renovating existing commercial buildings, Building Integrated PVs (BIPV) are gaining attention. The PV modules are directly integrated into

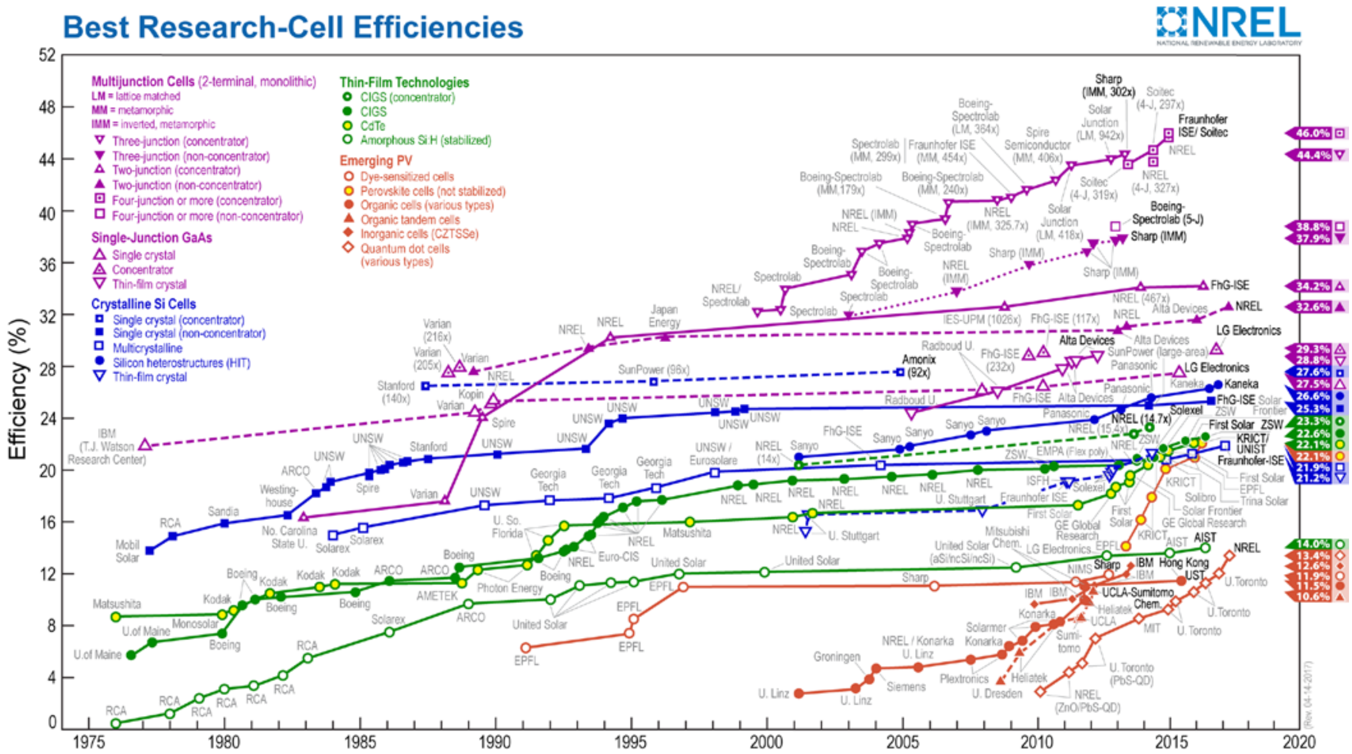


Figure 3.6 Best Research Cell Efficiencies. Source: US National Renewable Energy Laboratory

building elements such as roofs and façades without compromising a building's aesthetics.

BIPV modules are available in several forms including products designed for flat and pitched roofs, facades and glazing systems. The most widely installed to date is the thin film solar cell, which is integrated into a flexible polymer roofing membrane on flat roofs but solar shingles – which are designed to look and act like regular shingles but incorporating a flexible thin film cell – are getting more traction.

(Semi) transparent modules, which can be used to replace a number of architectural elements made with glass, such as windows and skylights, are also common.

Efficiency and performance of PV systems

A PV module consists of multiple PV cells interconnected and encapsulated. These cells represent the smallest unit in a PV power-producing device, typically available in 12.5 cm, 15 cm and up to 20 cm square sizes.

PV modules are typically rated between 50W and 300W, with specialized products for building integrated PV systems in larger sizes.

The key component of any PV power system is a PV array, which consists of a number of modules connected in a series, then coupled in parallel to produce the required output power, the mounting structure for the array, the inverter (essential for grid-connected systems and required for most off-grid systems), the cabling and, preferably also the storage battery and charge controller.

Module costs account for about 50% of system costs, so the costs associated with Balance of System technologies – which include all other system components – need to be reduced.

The type of compensation offered to building owners who generate electricity from a PV-system will determine how that system is configured. If there is a feed-in-tariff, the PV array should be oriented north to maximize solar radiation. For net metering and time-of-use tariffs, a western orientation will likely maximize any compensation.

Depending on market regulations, PV systems with storage can accommodate a plethora of other grid services that generate revenue.

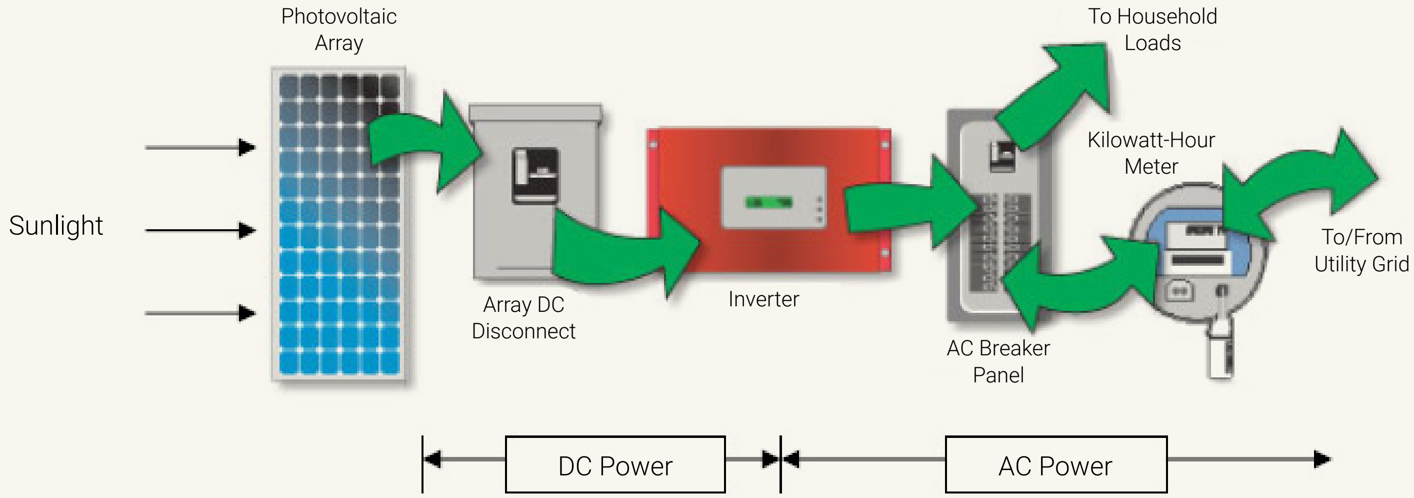
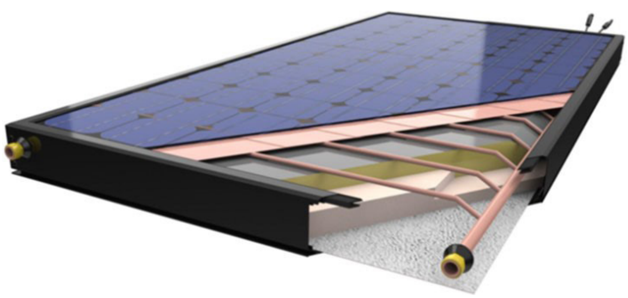


Figure 3.7 Basic components of any PV system in a commercial building.
Source: eia.gov

Below: Liquid PVT
Bottom: Air PVT



Hybrid PV Technologies

PV thermal hybrid solar collectors, sometimes known as hybrid PV/T systems or PVT, are systems that convert solar radiation into thermal and electrical energy. These systems combine a PV cell, which converts electromagnetic radiation into electricity, with a solar thermal collector, which captures the remaining energy and removes waste heat from the PV module. The engineered cooling of PV cells improves their efficiency.

Hybrid technologies capture electricity and heat, making them more energy efficient than solar PV or solar thermal. PVT modules are available in configurations that can produce hot water or warm air, along with electricity generation.

Wind generators

Changes in planning standards have created opportunities for small-scale wind power.

The wind power sector is now developing small turbines, with rotors of up to 5m diameter, installed capacities from 1kW up to 200kW, and hybrid systems combined with PVs. However, builders have to keep in mind that a halving of wind speed cuts power by a factor of eight.

In rural areas, a good site can record wind speeds of more than 6 metres per second (m/s). However, average wind speeds rarely exceed 1 or 2m/s. In addition, rough terrain around a building often produces poor wind conditions. So, a PV system will likely produce a better return on investment than a small, roof-mounted turbine.

In comparison, a commercial building on the outskirts of a city's, where building density is usually lower and air flow patterns cleaner, would provide a better platform for a small wind turbine. However, prevailing microclimate conditions should be carefully monitored.

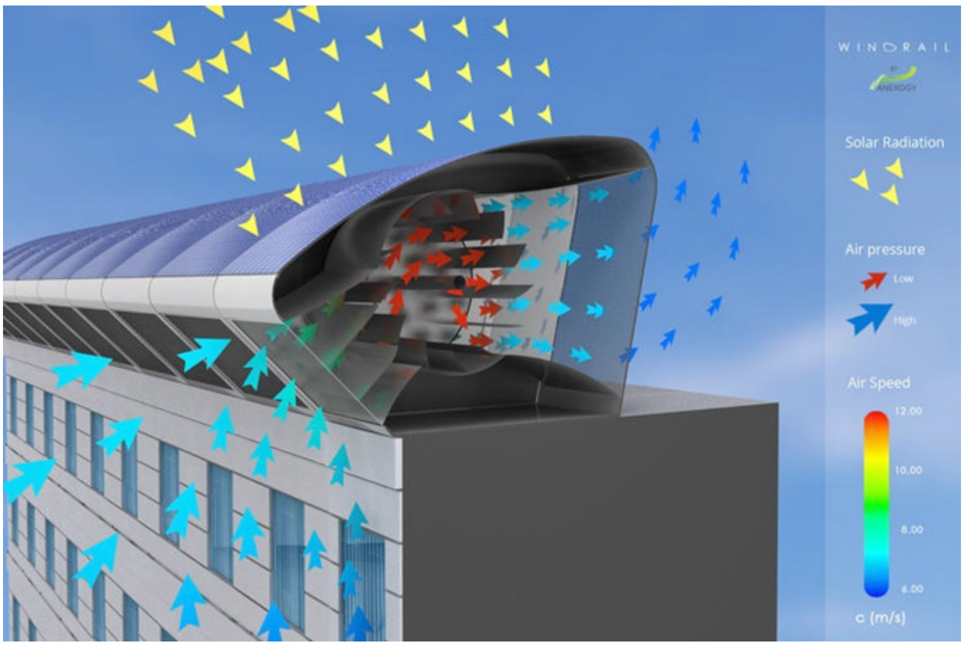


Figure 3.8 An integrated system with a radial wind turbine (20kW) and two PV panels (2*40 kW).
Source: Anerdgy

FMSA wanted a cost-effective, low-carbon retrofit. Photo: Commercial Property Guide

182 Capel St (Melbourne)

182 Capel St is a small commercial building built in 1984. In 2003, architects Fooks Martin Sandow Anson (FMSA) bought the building in the hope of refurbishing it along sustainable guidelines. The building's mechanical systems were at the end of their life and its generator and sub-station were removed after a couple of years.

Snapshot

Year built 1984

Location 182 Capel St, Melbourne, VIC

Size (NLA) 1,600m^2

Tenancy Offices (3 floors) and basement

Refurbishment 2008 – 2011

Project costs $416,012 plus $1.4M per additional floor

NABERS Energy Initial: 1.5, Target: 5.0

NABERS Water Initial: 1.5, Target: 4.0

Key features

- Windows, external blinds controlled by economy cycle system
- Gas-fired VRF heat pump air conditioning
- Rainwater collection tanks in basement
- Green facades installed on building's western side
- Intelligent BMS
- LED, fluorescent lamps controlled by occupancy sensors
- Ceiling fans
- Extra building insulation and sealing (slabs and windows)

Energy saving Electricity: 150 kWh/day per floor, Gas: 258 MJ/day per floor

Water saving 900 L/day from 1600 L/day

Greenhouse saving 81 tonnes CO_2/floor/p.a. from 190 tonnes/floor/p.a.

Annual saving $22,206

182 Capel St is a good example of a low-energy refurbishment. Photo: Commercial Property Guide

The low-carbon retrofit was partly funded by a grant from the Federal Government's Green Building Fund. FMSA held a workshop to identify constraints and challenges, and determine the suitability and affordability of proposed solutions.

Objectives:

- Cut energy consumption and carbon emissions by at least 50%
- Achieve 5.0 Star NABERS Energy rating
- Achieve 4.0 Star NABERS Water rating

Features and Implementation:

Building structure

- Minor upgrade of building structure
- Operable windows installed for natural ventilation
- Window systems connected to a weather station which informed mechanical systems about changes in air temperature, enabled automatic opening and closing of windows and activated air conditioning when necessary
- Additional insulation installed in parts of the building
- Double-glazing installed on the first floor; automated external blinds fitted to seal the building at night and during certain times of the year
- Green facades located on western side of the building. Planter boxes on balconies designed to support climbing vegetation

Heating, ventilation, and air conditioning

- Gas-fired VAV systems installed with a condenser in each floor
- Gas engines located at ground level for easier inspections, better noise control, less structural costs
- Engine speeds changed according to demand
- Cooling and heating systems integrated and micro-controlled by BMS
- Ceiling fans installed

Lighting and energy load

- Additional emphasis put on lighting power demand and energy efficient office equipment
- Combination of fluorescent and LED lights controlled by occupancy sensors in some areas, manually in others
- Artificial lighting reduced to a minimum in summer

Building management and controls

- Simple, flexible and cost-effective BMS installed to control HVAC, windows and lighting
- Each floor separately monitored and metered

Outcomes:

- 5 Star NABERS Energy rating achieved without GreenPower
- Energy consumption cut by 38%; CO_2 emissions by 49%
- Peripheral energy consumption cut out-of-hours
- More than 80% of employees joined the company's sustainability drive

Read more at: melbourne.vic.gov.au and sbenrc.com.au

SECTION

04

Carbon Footprint Analysis

You cannot manage what you cannot measure. Carbon footprint analysis offers techniques to assess the current state of a building's emissions and measure the impact of energy conservation and alternative mitigation strategies.

Measuring the impact

In recent years, environmental sustainability has emerged as a key issue for governments, business, researchers and the public. Two key processes have emerged to help organisations measure and address the impact they have on the environment in a cost-effective way: the carbon footprint, and building energy-saving analysis.

Studies have shown we could cut emissions from residential and non-residential buildings by more than 90% by 2050, and recover the costs of doing so over a reasonable time period, if we:

- Reduced the energy demand in new buildings as much as possible
- Made old buildings much more energy efficient
- Used renewable energy for heating, cooling and cooking

The total amount of greenhouse gas produced to directly and indirectly support human activity is usually expressed in equivalent tons of carbon dioxide (CO_2). By measuring a building's carbon footprint, the developer/owner can see how much greenhouse gas is produced, directly and indirectly, to construct and operate the building.

Six greenhouse gases have been identified by the Kyoto Protocol:

- **Carbon dioxide (CO_2)** is primarily produced when fossil fuels are burnt to make aluminum, steel, cement and glass
- **Methane (CH4)** is emitted when organic material is burnt or decomposes, and when gasoline and natural gas are produced or refined
- **Nitrous Oxide (N2O)** is emitted when solid waste is incinerated, from fertilizers, and from some forms of transport
- **Hydrofluorocarbons (HFC)** are a by-product of the industrial processes used to make insulation, refrigeration and air-conditioning
- **Perfluorocarbons (PFC)** are a by-product of aluminum production
- **Sulphur hexafluoride (SF6)** is used in insulation and in current interruption in electricity transmission and distribution equipment and electronic systems

CO_2 equivalent acts as a common measurement of how much global warming a given type and amount of greenhouse gas may cause. It normalizes the impact of all other gases to that of CO_2.

For the commercial sector

Governments are beginning to regulate carbon footprints for the building sector but the primary driver of any decision to retrofit remains the need to replace aging equipment and building elements, and the desire to improve the indoor environmental conditions for building tenants. For new buildings, low carbon design must be integrated into the overall building design, which will affect its energy performance.

Carbon footprint analysis quantifies the CO_2 emissions over a building's life. Similar tools include Life Cycle Analysis (LCA), Ecolabel, Environmental Management Systems (ISO 14001) and Energy Management Systems (ISO 50001).

The different concepts and methods these tools deploy are assessed in the table below.

Input data required for different types of commercial buildings

Carbon Footprint Analysis is the mapping of greenhouse gas emissions associated with an activity or group of activities of a product or process. Sources of greenhouse gas emissions are organized by scopes:

- **Scope 1**: Direct emissions related to an organization's operation, activities and processes (e.g. gas and transport fuels). Scope 1 emissions can be divided into two categories: emissions associated with fuels consumed directly (liquid and gaseous fuels); and emissions from refrigerant gases used in air-conditioning and other gases, such as methane from organic waste etc.
- **Scope 2**: Indirect emissions derived from electricity used for a company's operation (lighting, appliances and equipment, cooling), including transmission and distribution losses, as well as in boundary transportation and stationary fuel combustion.
- **Scope 3**: Indirect emissions embodied in products and services (food, clothing, building materials). For most organisations, this relates to business trips and waste.

Scope 3 also includes the following:

- Staff business travel, including by plane, train, bus or car
- Staff commuting. Businesses are increasingly encouraging their staff to travel to and from work by public transport, where possible
- Water consumption: Water accounts for only a small part of any carbon footprint. However, it is a

Tools to quantify the CO_2 emissions over a building's life

Tools	Type	Approach	Application	Emissions	Related standards	Relation with other tools and standards
LCA	Process tool	cradle to grave	per process per product	Air emissions, solid and liquid waste	ISO 14040 -14044	ISO 14000, ISO 50001, Environmental Rating Systems (LEED, BREEAM)
Carbon Footprint Analysis	Process tool		per person, per household per process per product	Greenhouse gases	PAS 2050 ISO 14064-65	
Ecolabel	Process tool		per product	Air emissions, solid and liquid waste	ISO 14040 -14044 and PAS 2050 ISO 14064-65	
Environmental Management Systems (EMS)	Analytical tool	evaluation of all environmental aspects	per organization	Air emissions, solid and liquid waste	EMAS, ISO 14001	ISO 14040 -14044
Energy Management Systems	Analytical tool	evaluation of energy consumption	per organization	-	ISO 50001	ISO 14001, EMAS

precious resource that should not be wasted. The amount of water used in a building is also a useful measure of the conditions of the building's services

- Waste: What and how much waste, and how it is disposed, should be measured

Data processing: Environmental evaluation

A carbon footprint can be calculated using a bottom-up method based on Process Analysis (PA); or, from the top-down, based on Environmental Input/ Output (EIO) analysis. Both methods aim to capture the full life-cycle impacts.

Process analysis can be used to calculate the environmental impact of individual products from creation to disposal. However, this method suffers from a system boundary problem: only on-site, mostly first-order, and some second-order impacts are considered. That means appropriate system boundaries must be identified to minimize this truncation error.

This method also encounters problems when applied to larger entities such as households, governments and industrial sectors. An environmental input-output (EIO) analysis is therefore a useful alternative method of measuring any carbon footprint. Input-output tables provide a picture of all economic activities at a sector level. Combined with consistent environmental account data, they can establish a robust and comprehensive carbon footprint, taking into account higher-order impacts and setting the whole economic system as the boundary.

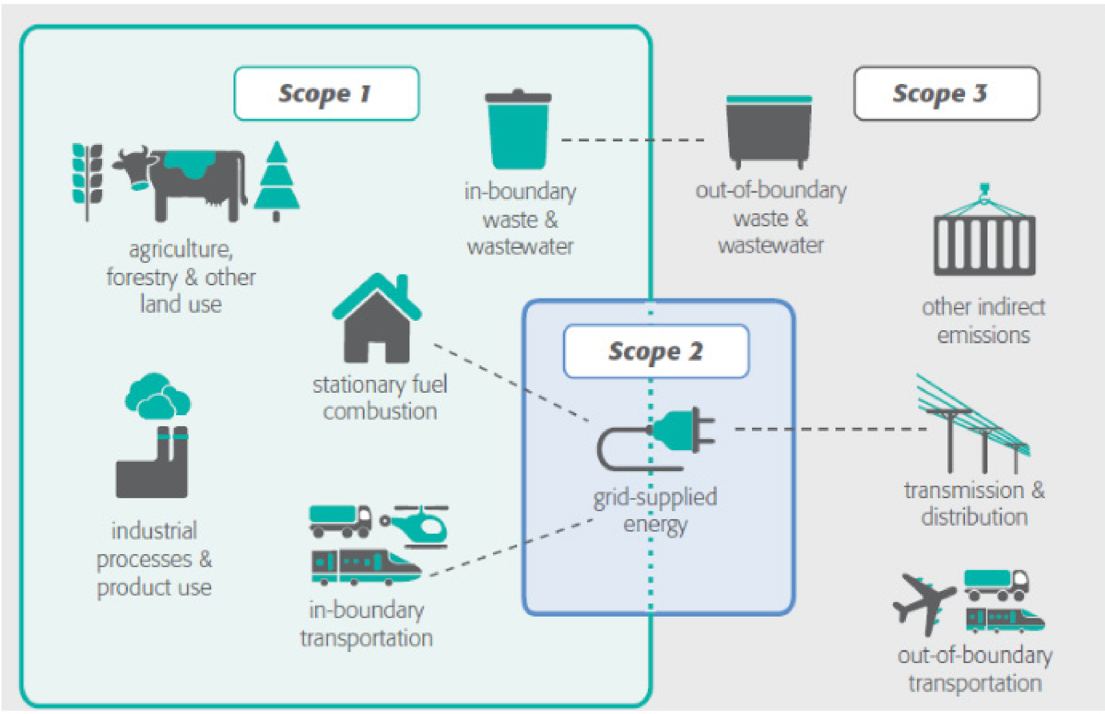


Figure 4.1 Emissions are generated by a range of activities.
Source: Fong et al., 2014//boundary: limit of the system

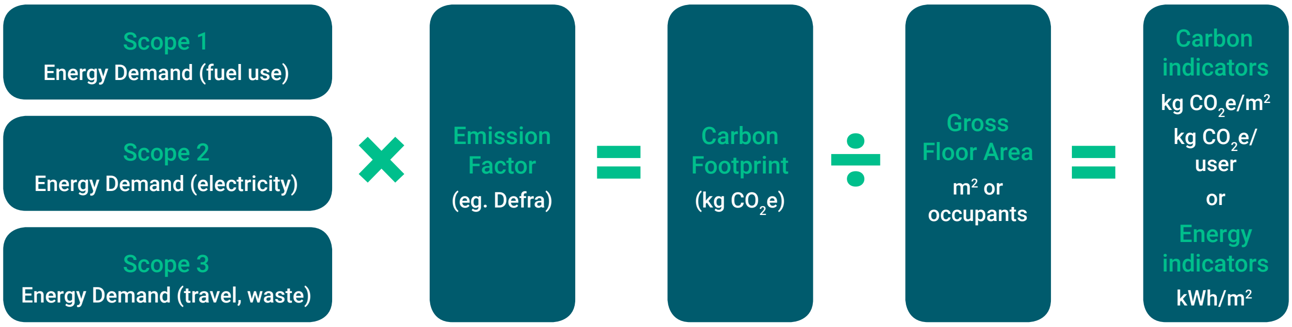


Figure 4.2 Methodology for calculating a carbon footprint.
Source: Agis Papadopoulos 2019

The main calculation methodology for evaluating and quantifying a carbon footprint can be seen above. The energy demand registered from the three different scopes is calculated with the emission factors, which are selected by recognized databases. To achieve sufficient monitoring, carbon indicators and benchmarking are set to evaluate the building or system under scrutiny.

These two organisations can be referred to regarding the analysis of carbon footprint emission factors:

- The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change. It was established by the United Nations Environment Programme and the World Meteorological Organization to provide a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts.
- UK Department of Environment, Food and Rural Affairs makes policy and legislation, and works with other bodies to deliver policies in areas such as the natural environment, sustainable development and the green economy. Its emission factors are periodically updated.

Organisations that monitor energy demand and measure their carbon footprint have an advantage over their competitors because their energy demands and operating costs are lower, and they have less trouble complying with new environmental legislation, standards and national emission plans.

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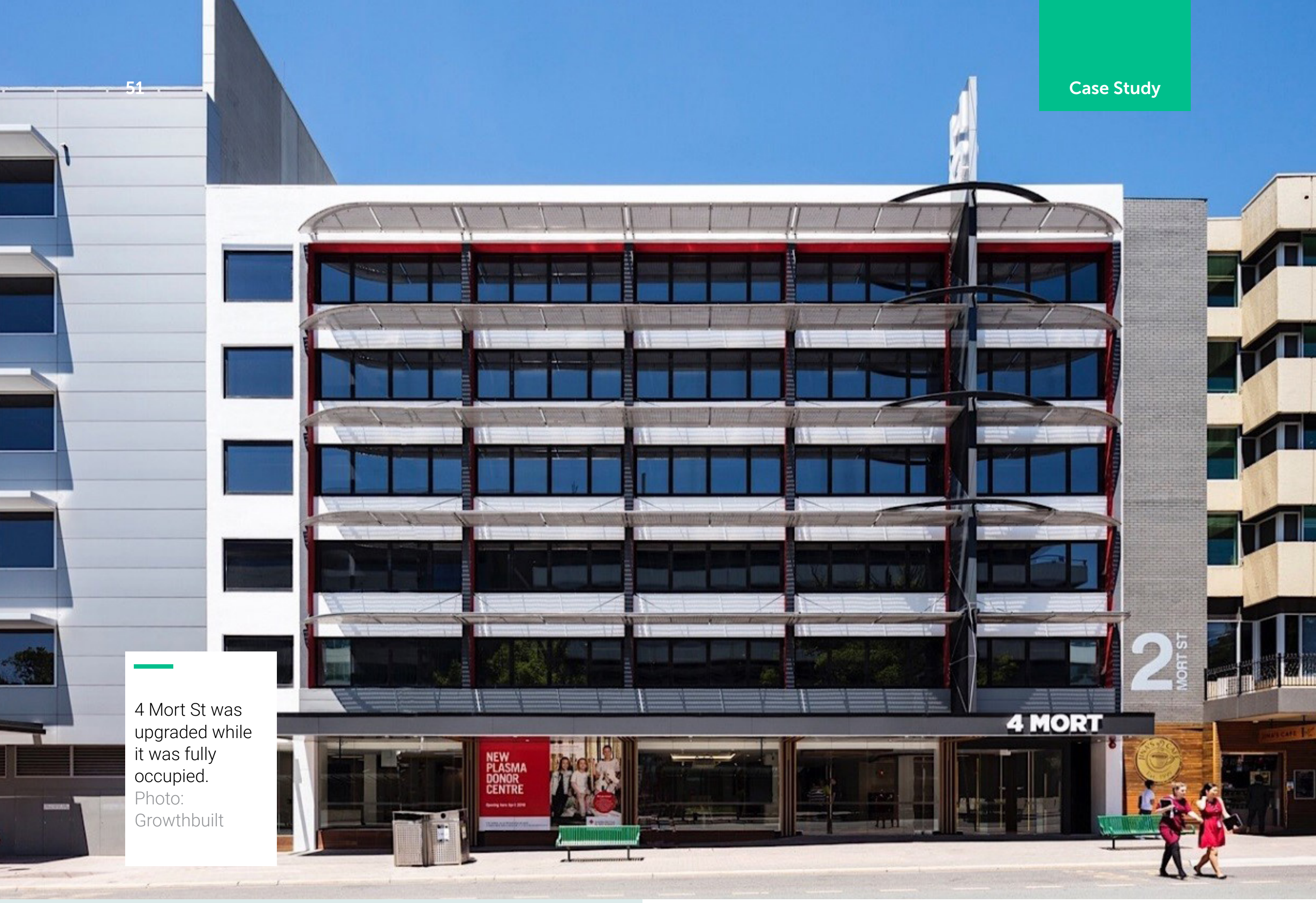


4 Mort St was upgraded while it was fully occupied. Photo: Growthbuilt

4 Mort St (Canberra)

By 2009, the existing HVAC system at 4 Mort St was unreliable and expensive to maintain. So, in 2010, Trafalgar Platinum Fund decided to upgrade the building to improve its energy performance to achieve an increase from a 2.5 to 4.5 star NABERS Energy rating.

Snapshot

Year built 1966

Location 4 Mort St, Canberra, ACT

Size (NLA) 5,400m^2

Tenancy 6 storeys

Refurbishment 2009 – 2010

Project costs $1M plus $0.5M from Green Building Fund

NABERS Energy Initial: 2.5, Target: 5.0

Key features

- New BMS incorporating energy-smart controls, chilled water reset, night purge, economy cycle, VAV controls
- Sensors
- BMS monitoring of energy consumption of chiller, electronic motors, thermal energy for chilled and heated water systems, and mechanical switch board
- Optimised chiller and boiler plant efficiency
- Magnetic-bearing centrifugal chiller with air-cooled condenser
- Fuel-switching from electricity to gas for indoor heating
- Additional thermal insulation in all new pipe work, air distribution ducts, pumps, valves, flanges and strainers
- Dichroic type lights replaced with LED
- Low-cost motion sensors, automatic lighting controls

Energy saving 70% cut in energy consumption p.a.

Greenhouse saving 70% cut in CO_2 emissions p.a.

Annual saving $120,000

Top: Thermal insulation was applied to all pipeline components. Middle: A chilled water buffer vessel in the building at 4 Mort St.

The budget was only $1.5M and the building remained occupied during the upgrade, which had to comply with Energy Efficiency in Government Operations Policy requirements for Australian Government tenants, and the ACT Environmental Leasing Policy for Territory Government tenants.

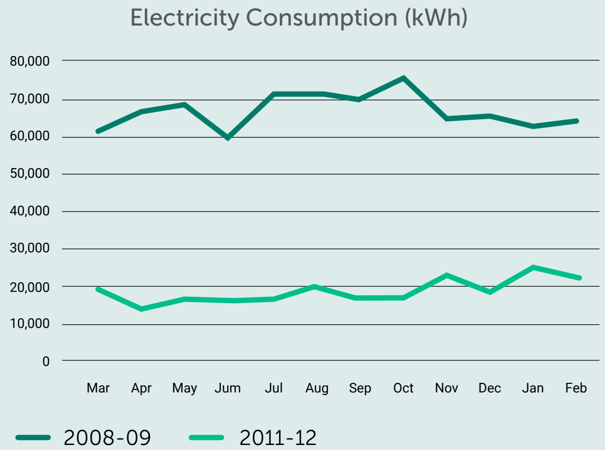
Objectives:

- Perform a level 2 energy audit and building simulations to propose a set of recommendations for upgrading HVAC plant and lighting systems
- Significantly reduce energy consumption and carbon emissions
- Achieve 5 star NABERS Energy rating

Features and Implementation:

After the energy audit and building simulation:

- BMS installed incorporating energy smart control functions, chilled water reset, night purge (using cooler ambient air at night time to pre-cool the space), an economy cycle, and VAV control (including feedback from CO_2 and duct velocity sensors)
- BMS sensors installed in case of unforeseen challenges during commissioning and fine-tuning
- BMS monitoring features used for energy consumption of the chiller, electronic motors, thermal energy for chilled and heated water systems, and mechanical switch board
- Chiller and boiler plant efficiency optimised
- A magnetic bearing centrifugal chiller with air-cooled condenser installed
- A fuel-switching system from electricity to gas included for indoor space heating
- Additional thermal insulation applied to all new pipe work, existing accessible air distribution ducts pumps, valves, flanges and strainers
- Inefficient dichroic type lights replaced with LED fittings
- Low-cost motion sensors and automatic lighting control devices installed in lift lobbies, toilets, carpark, entrance lobby and on external lighting



Source: Department of the Environment and Energy

Outcomes:

- An improvement from 2.0 to 4.5 star NABERS Energy Rating
- Improved monitoring systems
- Increased asset value of $1.4M
- 70% reduction in annual greenhouse gas emissions
- Annual energy cost savings of $120,000

Read more at: energy.gov.au

SECTION

05

The economics of Low Carbon Refurbishment

The economics of low carbon buildings should be analysed to both ensure ongoing financial performance and to supply evidence for advocacy for low carbon and energy efficiency initiatives over the building's life cycle.

There is no doubt that the low-carbon refurbishment of any commercial building costs money. So, organisations thinking of embarking on such a project must first decide whether it will compromise their profits. They must weigh the value of decarbonising a property against the financial returns they hope to get from the property.

Growing environmental awareness and an increasing emphasis on Corporate Social Responsibility in the business world means property developers and owners are beginning to re-assess the costs associated with sustainability, whether that be the length of any pay-back period, the greater marketability of a sustainable building or an improved public profile for the building's owner or developer.

High-tech product retailers, companies active in energy and environment sectors and organisations targeting a young clientele are increasingly willing to pay a premium for office space in a sustainable building. Likewise, some companies that are less environmentally friendly also want to demonstrate 'green' credentials by operating out of a low-carbon building.

Government services, local authorities and NGOs are increasingly adopting 'green' procurement strategies. And large, labour-intensive organizations that employ highly-qualified staff – software producers, law firms, international consultancies, healthcare providers – often demand high indoor environmental quality in buildings to maximize the well-being and productivity of their staff.

Life Cycle Cost Analysis

Life cycle cost analysis (LCCA) uses a discounted cash flow method to calculate the net present value of the life cycle costs. The International Organization for Standardization's ISO 15686 is used to define LCCA, in addition to the principle of whole life cycle costs for managing the long-term cost assessment of capital projects.

The methodology is well developed and standardized, but in practice, problems arise because of a due a lack of reliable data and benchmarks.

Traditionally, LCCA has been used to assess direct costs such as energy, building renewal and replacement, and operation and maintenance, but it can also be applied to indirect costs such as staff salaries, staff productivity, lost construction time, fire insurance, lost revenues due to downtime, and other costs not directly related to the cost of the building. Indirect costs are often more difficult to estimate but they are significant and should be considered.

It is important to keep in mind that LCC extrapolates existing and future costs to convey both as a base for making optimum choices. However, developers often ignore LCC because they regard it as a 'theoretical' analysis of costs incurred in the distant future, compared with a more traditional and tangible capital cost assessment. Many developers also disregard LCC because they won't own a building long-term and therefore don't feel they have to account for long-term costs. This shortcoming of 'traditional' investment appraisal methods can only be addressed by adopting energy and environmental assessment and certification schemes.

Levelized Cost of Conserved Energy and of Carbon Emissions Avoidance

Because LCC addresses the overall costs of a building, you need a methodology that focuses on energy and environmental issues. The concept of a Levelized Cost of Energy (LCOE) has been developed to compare energy supply technologies from an economic point of view and can be defined as the long-run 'average' cost of a unit of energy provided by a particular technology, calculated by taking into account the time value of money.

LCOE is a concept developed for energy generation, which is slightly different from the assessment of the value of energy conserved or of carbon emissions avoided. Therefore, the concept of Levelized Cost of Conserved Energy (LCCE) has been developed to

compare the cost of a unit of energy saved to the cost of purchasing the same unit of energy.

LCCE deduces the investment, operation and maintenance cost differences between a baseline technology and an energy-efficiency alternative, and divides this by the annual energy savings. It also considers the time value of money, by means of the capital recovery factor, which is influenced by the capital discount rate and the lifetime of the measure.

The conceptual formula for LCCE is essentially the same as that of LCOE[1]:

$$LCCE := \frac{CRF \cdot NPV(\Delta Lifetime\ Expenses)}{\Delta E} = \frac{Annuity\ (\Delta Lifetime\ Expenses)}{\Delta E}$$

Where
CRF = capital recovery factor
NPV = net present value of the expenses over a building's lifetime
ΔE = amount of energy saved annually

If operation and maintenance costs remain fairly constant over the building's lifetime, a reasonable assumption for a commercial building, then the LCCE can be calculated as follows:

$$LCCE = \frac{CRF \cdot \Delta I + \Delta O\&M}{\Delta E}$$

Where
CRF = capital recovery factor
ΔI = incremental investment costs of an energy saving or decarbonisation measure compared to the base case investment
ΔO&M = difference in annual operation and maintenance costs of the energy saving measures, compared to the base case without energy saving measures
ΔE = the annual energy conserved by the measure, compared to the energy consumed when using the base case technology

An advantage of LCCE is that it works with the difference between the energy efficient and the base case scenario; it does not include the annual fuel cost difference. On the other hand, a disadvantage compared with LCC is that it can't consider any additional monetary benefits, such as reductions in contractual charges, or increases in rental prices. They have to be taken into account indirectly, as part of the operations and management difference, or by introducing additional terms to the equation.

The main advantage of LCCE is that it provides a metric for the benefits from energy conservation investments, which are independent of the energy price, and can be compared to different energy purchasing cost values for determining the profitability of the investment.

One of the difficulties in using any life cycle analysis is that the life time of various technologies may differ. So, replacement costs need to be considered as future costs.

A typical example is the replacement of an incandescent lamp with either a compact fluorescent (CFL) or an LED lamp, which may live up to 10 or 20 times longer, respectively. When calculating the LCCE for the two lamps, the multiple replacement costs for the incandescent lamp have to be considered as avoided investment costs, along with the reduced energy consumption. In such a case, it's possible to arrive at a negative annualized LCCE result, because the investment is already profitable at the investment level thanks to avoiding replacing the incandescent lamp 10 or 20 times, without even considering the value of the energy savings.

LCCE also suffers from the 'principal-agent problem' where a developer might be motivated to act in their own best interests when it comes to constructing a building, rather than in the interests of future owners of the building. LCCE can, however, be linked directly to energy and environmental certification schemes, in order to demonstrate the feasibility of low carbon design and refurbishment.

End Notes

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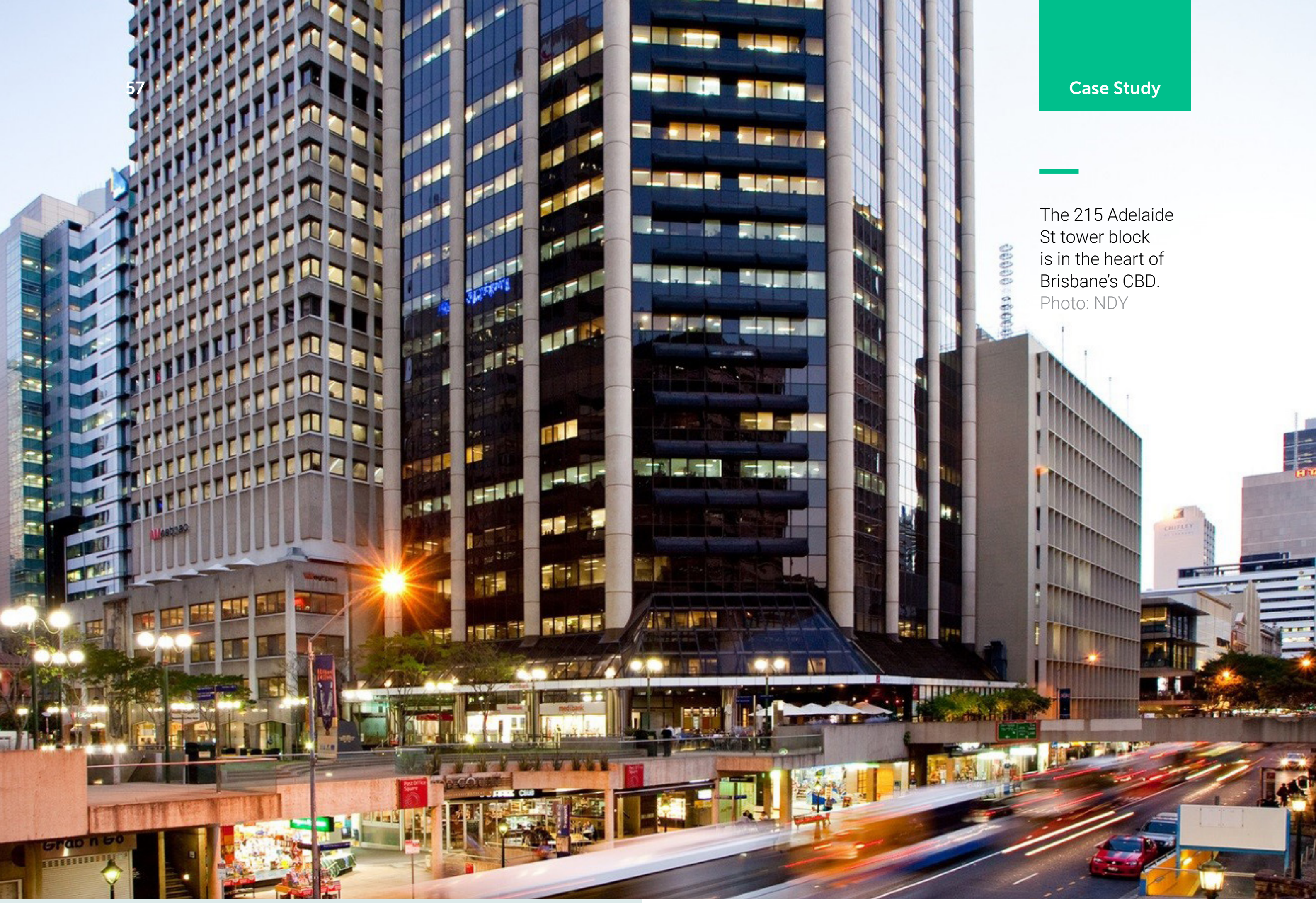
Case Study



The 215 Adelaide St tower block is in the heart of Brisbane's CBD. Photo: NDY

215 Adelaide St (Brisbane)

The commercial tower at 215 Adelaide St was built more than 30 years ago. In 2008, engineering consultancy Norman Disney & Young (NDY) was commissioned to do a NABERS energy assessment to determine upgrade options. The energy modelling provided a strong foundation for a scope of major building works to be agreed with the building owner, and it was hoped the building's NABERS Energy rating would rise to 5 stars from 2.5.

Snapshot

Year built 1970s

Location 215 Adelaide St, Brisbane, QLD

Size (NLA) 1,600m^2

Tenancy Offices

Refurbishment 2008 – 2013

Project costs $5.4M

NABERS Energy Initial: 2.5, Target: 5.0

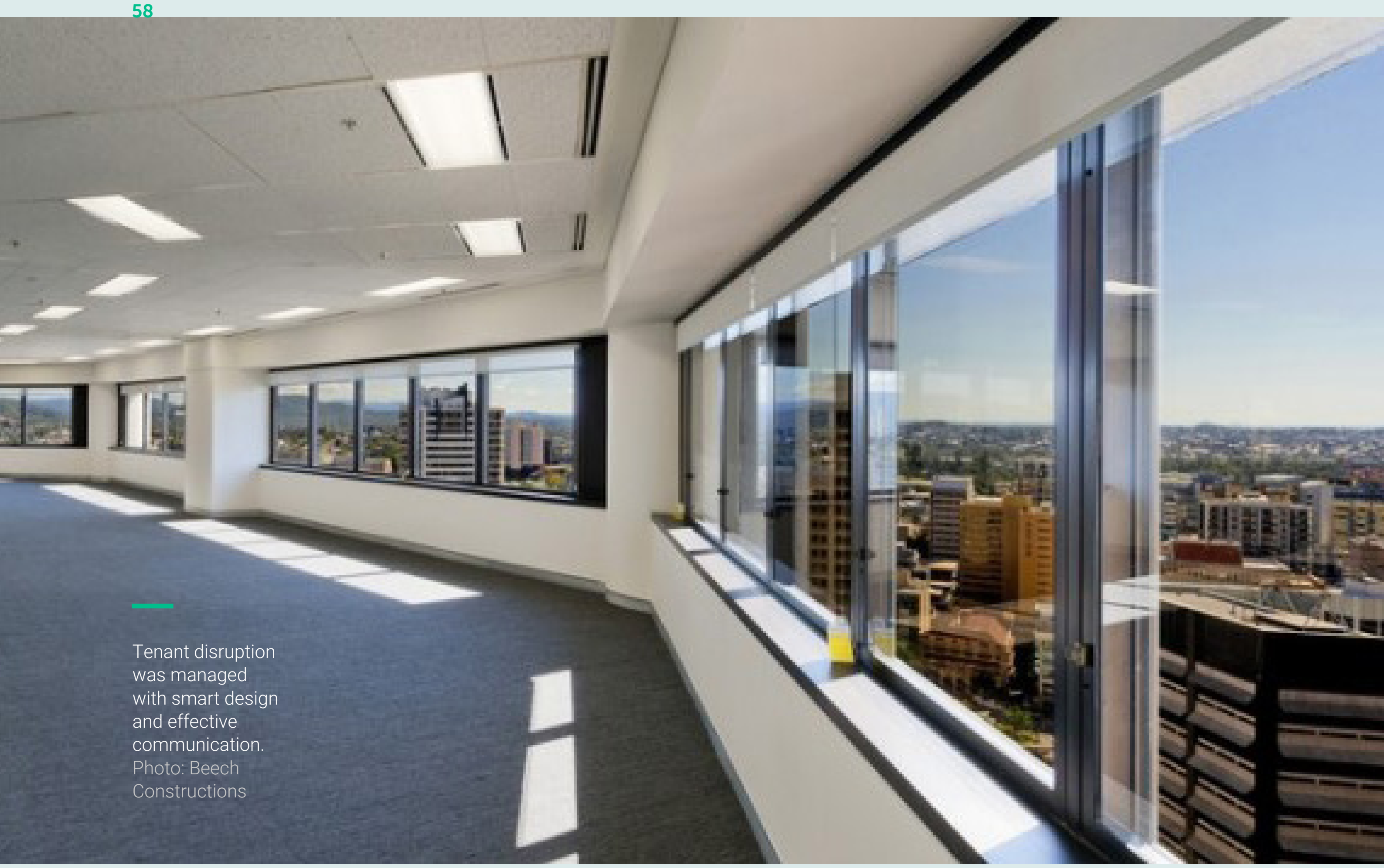
NABERS Water Target: 4.5

Key features
- Upgraded lighting lamps
- Improved electronic control gear for lighting system
- Custom reflectors and Y5 refractors for single tube luminaire for uniform lighting, low glare
- New tenant lighting controls
- Chilled water thermal energy system, fan speed modulation
- Existing AHU reprogrammed to improve flexibility, control
- Chilled water energy meters installed; extra smart metering

Energy saving 50% cut in energy consumption p.a.

Greenhouse saving 46% cut in CO_2 emissions p.a.

Annual saving $460,000



Tenant disruption was managed with smart design and effective communication. Photo: Beech Constructions

In 2010, the building underwent a comprehensive $5.4M building services upgrade. Lighting throughout the building comprised twin 36W tube recessed troffer luminaires with clip-on light-air boots mounted in a one-way ceiling grid. There were significant risks associated with the luminaires supporting the ceiling tiles and wholly supporting the supply air diffusers. The upgrade included NABERS thermal energy modelling, NABERS pre-commitment certification, and fine tuning and monitoring.

Objectives:

- To significantly reduce energy consumption and carbon emissions
- To achieve a 5 star NABERS Energy rating

Features and Implementation:

The following upgrades were implemented:

- Existing lighting upgraded to single lamp T8, increasing energy savings by 50% or 50W per luminaire
- Electronic control gear of the lighting system significantly improved
- Single tube luminaires specified with custom reflectors and Y5 refractors to ensure excellent lighting uniformity and low glare
- New tenant lighting controls
- Chilled water thermal energy system and fan speed modulation installed throughout the building
- Existing AHU retained, reprogrammed and fine-tuned to improve control and provide a constant multi-zone control
- Extensive chilled water energy metering was installed within existing pipe work, and additional smart metering of power supplies was connected to the central chilled water plant

Outcomes:

- A 5 star NABERS Energy rating equating to a 50% cut in energy consumption (5Mwh/p.a.)
- A 46% cut in CO_2 emissions (4,500 tonnes) p.a.
- Electricity savings of $460,000 p.a.

Read more at: ndy.com

SECTION

06

Environmental evaluation

There are a number of sophisticated and mature environmental evaluation frameworks available both in Australia and overseas. These can be used to ensure compliance and/or to demonstrate to the public superior performance above and beyond code requirements.

The management of sustainable buildings is a complex problem that requires a range of tools and which must always consider prevailing environmental policies and legislation.

Building rating systems rate relative levels of compliance with and performance of specific environmental and sustainability goals and requirements, giving owners, tenants and other stakeholders a way to distinguish among efficient and inefficient buildings. The ratings can evaluate new and existing buildings.

Internationally, the most popular certification schemes are the Building Research Establishment Environmental Assessment Method (BREEAM), the U.S.'s Green Building Council (LEED), Deutsche Gesellschaft fur Nachhaltiges Bauen (DGNB), and High Environmental Quality (HQE). Australia, has established the National Carbon Offset Standard (NCOS), the National Australian Built Environment Rating System (NABERS) and Green Star.

All methods consider energy and water consumption, indoor environmental quality, the materials and resources used in a building and its operational management. The methods differ in the importance they attach to various evaluation criteria. For example, BREEAM considers transport and pollution separately, while LEED incorporates them into energy efficiency and sustainable site management parameters.

Nevertheless, energy efficiency in all rating systems accounts for more than 20% of the total certification score. BREEAM's energy criteria are linked to European legislation, while LEED's energy criteria are based on the standards ASHRAE 90.1 and 189.1. Both schemes have been modified for international applications so their requirements are compatible with national legislation and standards.

The assessment methods can be compared based on the types of buildings examined, certification benchmarking, life-cycle phases covered during the evaluation procedure, and audit reviews before certification.

Most of the methods discussed are commercial tools developed within an academic framework, and supported by government agencies and authorities, and by industrial associations. Therefore, they focus both on sustainability in the building sector, and on economic and financial motivations as means of achieving increased energy efficiency.

For example, low and off-peak energy consumption, water savings and waste management can reduce operating costs but also increase a building's market value because of its sustainability certification.

Certification also assesses indoor air quality and thermal comfort. In that sense, green certification aims to improve the quality of living and the productivity of a building's users.

Environmental rating systems can also be applied on a building's neighbourhood level, for example, how urban greening and shading, or the use of cool materials can affect the heat island effect and establish better overall environmental conditions, hence having an impact on the building itself and on its users.

When it comes to building materials, certified materials are rated higher, as are local products, certified producers, and materials with low environmental impact. Materials represent about 12% of any green certification, compared with 19% for energy efficiency, and 15% for users' health and wellbeing. Using 'cool' materials in a building can make a big difference to temperatures in local neighbourhoods.

National Carbon Offset Standard (NCOS)

NCOS is a voluntary standard to manage greenhouse gas emissions and to achieve carbon neutrality. It provides best-practice guidance on how to measure, reduce, offset, report and audit emissions for organizations, products and services, events, precincts and buildings.

The standard can be used in several ways. Organizations can use it to better understand and manage their carbon emissions, to credibly claim carbon neutrality and to seek carbon neutral certification.

Measuring emissions and evaluating how much to cut is the most crucial step in the cycle because an organisation can then prioritize action. This can be achieved through a green house gas inventory that aims to:

- Define a system's operations, activities, units and processes
- Define and evaluate direct and indirect emissions
- Calculate the carbon footprint
- Suggest improvement measures

What needs to be measured will determine which of the many carbon calculators you choose to use. Some, for example, only factor in cars, aircraft and household energy use. Others also cover household waste and leisure interests.

The following offset units are eligible under NCOS:

- Australian Carbon Credit Units issued by the Clean Energy Regulator in accordance with the Carbon Credits (Carbon Farming Initiative) Act 2011
- Certified Emissions Reductions issued under the Kyoto Protocol from Clean Development Mechanism projects
- Removal Units issued by a Kyoto Protocol country on the basis of land use, land-use change and forestry activities
- Verified Emissions Reductions issued by the Gold Standard
- Verified Carbon Units issued by the Verified Carbon Standard

National Australian Built Environment Rating System (NABERS)

NABERS can be used to measure a building's energy efficiency, carbon emissions, water consumed, and waste produced, and to compare its performance with that of similar buildings. Once a building's environmental impact is quantified it can be improved. NABERS evaluates residential and office buildings, shopping centers, data centers and hotels.

The following commercial buildings can be certified under NABERS:

Shopping centers

The NABERS rating for shopping centres assesses and rates all services provided by a shopping centre owner to its retail tenants, and the centre's associated back-of-house requirements. This includes:

- All services provided to common areas
- Air-conditioning provided to tenants
- Water consumption across retail applications
- Car parks
- Vertical transportation in common areas
- Exterior lighting and signs

NABERS ratings for shopping centres are based on actual operational data related to the central services or common areas controlled by the shopping centre owner, over a 12-month period.
A shopping centre can be rated based on its energy use or its water use or both.

Office buildings

There are four different types of NABERS ratings for offices: energy, water, waste and indoor environment.

Energy ratings compare a building's energy consumption with a set of benchmarks based on actual data. The efficiency of an office building can be measured and rated for the base building, for the tenancy or for the whole building.

- Base Building Energy ratings are for buildings where central services such as heating, cooling, lifts and lobby lighting are rated
- A Tenancy Energy rating rates the space tenants occupy within a building
- A Whole Building Energy rating is for the base building and the space occupied by a tenant space. It is most often used when there is a single tenant occupying an entire building

Water ratings focus how much water is used and recycled in a building. Waste ratings measure the amount of waste a building generates including materials that are recycled.

Indoor environment ratings measure the indoor air quality, lighting quality, temperature and thermal comfort, and the acoustic quality of a building. This is broken into ratings for base building, tenancy and whole building.

Efficiency indicators are used to classify buildings according to their environmental performance, as shown in this table.

NABERS energy benchmarking for office buildings

Total energy use in MJ	MJ per annum
Total energy intensity	MJ/m^2 per annum
Electricity energy intensity	MJ/m^2 per annum
Gas energy intensity	MJ/m^2 per annum
Coal energy intensity	MJ/m^2 per annum
Diesel energy intensity	MJ/m^2 per annum
Total greenhouse emissions (raw), Scope 1, 2 & 3	**kg CO_2 per annum**
Greenhouse emissions intensity (raw), Scope 1, 2 & 3	kg CO_2/m^2 per annum
Electricity greenhouse emissions (raw), Scope 1, 2 & 3	kg CO_2 per annum
Gas greenhouse emissions (raw), Scope 1, 2 & 3	kg CO_2 per annum
Coal greenhouse emissions (raw), Scope 1, 2 & 3	kg CO_2 per annum
Diesel greenhouse emissions (raw), Scope 1, 2 & 3	kg CO_2 per annum

NABERS compares a building's performance to benchmarks that represent the performance of similar buildings in the same location. At least 12 months of real, measurable information about the building, such

Figure 6.1 NABERS star accreditation scale.

as energy and water bills or waste consumption data, are used. The data is normalized, that is, adjusted to account for the location and use of the building. The rating takes into consideration the following points:

- Building or workspace climate
- Operational characteristics (e.g. opening hours)
- Level of services provided (such as heated swimming pools in hotels)
- Energy sources
- Size and occupancy

The adjusted data is then compared with the NABERS benchmark data and a star rating is assigned.

Implementing NABERS is one of the most effective ways to demonstrate the energy efficiency and environmental benefits of a new or refurbished building. It provides a credible, independently verified means of benchmarking and monitoring actual improvements in energy and environmental performance. It also provides much-needed visibility and market recognition, leading to a competitive advantage for building owners and tenants.

This applies even more to the Carbon Neutral Certification, which is an extension of the NABERS Energy rating that takes into account the quantity of carbon a building is producing. Certification incorporates carbon offsets or carbon credits purchased to help make a building carbon positive. Carbon Neutral certification is only available for buildings with current NABERS Energy ratings of 4 stars and above.

Green Star

Green Star, launched by the Green Building Council of Australia in 2003, is the country's only national and voluntary rating system for buildings and communities. It aims to improve the environmental efficiency of buildings and the health and well-being of entire communities.

There are four Green Star ratings tools:

- Green Star – Communities, to certify a plan for a precinct-scale development
- Green Star – Design and As Built, to certify the design and construction of a building
- Green Star – Interiors, to certify the interior equipment of a building
- Green Star – Performance, to certify the operational performance of a building

Green Star ratings are available for practically every building type, including all types of commercial buildings, and are based on an assessment of the following:

- Management
- Environmental impact
- Building quality
- Energy
- Transport
- Water, materials, land use and ecology
- Emissions
- Innovation

The ratings, between one and six, assess the sustainability of projects at all stages of the built environment lifecycle.

Figure 6.2 Green Star accreditation scale.
Source: Green Building Council Australia

Leadership in Energy and Environmental Design (LEED) Certification

LEED is a voluntary, consensus-based international standard for developing high-performance, sustainable buildings, using a comprehensive, point-based system. With each new version, it raises the bar on the green building industry.

Initiated by the US Green Building Council in 2000 and internationally recognized, the certification confirms that a building is designed and built to achieve a performance that surpasses national standards for energy savings, water efficiency, CO_2 emissions reduction, indoor environmental quality, stewardship of resources and sensitivity to their impacts.

These topics are specified in seven categories, with multiple credits, on which the building is evaluated. LEED points are awarded per credit on a 100-point scale (+10 bonus points), resulting in four levels of performance: Certified, Silver, Gold and Platinum.

LEED is most popular in North America, but is also used around the world.

Building Research Establishment's Environmental Assessment Method (BREEAM)

BREEAM, developed in the UK by the Building Research Establishment, has heavily influenced European sustainability design and construction. It is an international standard that can be locally adapted, operated and applied through a network of operators, assessors and industry professionals.

Since its inception in 1990, more than 565,803 projects, and over 2,275,036 buildings in about 77 countries have been evaluated using BREEAM. All types of buildings can be certified, with scores for energy, water, transport, waste, materials, land use and ecology, pollution, and health and wellbeing.

Environmental impact categories and criteria for green ratings systems

Energy	Water
Reduction of CO_2 emissions	Water consumption
Energy monitoring	Water monitoring
Energy-efficient external lighting	Water leak detection and prevention
Low- and zero-carbon technologies	Water-efficient equipment (process)
Energy-efficient cold storage	**Waste**
Energy-efficient transportation	Construction waste management
Energy-efficient laboratory systems	Recycled aggregate
Energy-efficient equipment (process)	Operational waste
Drying space	Speculative floor and ceiling finishes
Transport	**Materials**
Public transport accessibility	Life-cycle impacts
Proximity to amenities	Hard landscaping and boundary protection
Cyclist amenities	Responsible sourcing of materials
Maximum car parking capacity	Insulation
Travel plan	Designing for robustness
Land use and ecology	**Pollution**
Site selection	Impact of refrigerants
Ecological value of site /	
protection of ecological features	NOx emissions from heating/ cooling source
Mitigating ecological impact	Surface water run-off
Enhancing site ecology	Reduction of night-time light pollution
Long-term impact on biodiversity	Noise attenuation
Health and wellbeing	**Management**
Visual comfort	Sustainable procurement
Indoor air quality	Responsible construction practices
Thermal comfort	Construction site impacts
Water quality	Stakeholder participation

How environmental evaluation works:

- A ratings guide explains how to acquire points in each sub-criterion
- The objective for each sub-criterion is presented
- The guide outlines best practise for each criterion, and lists benchmarks for evaluation. Checklists, tables and compliance notes provide additional information about the main assessment criteria
- How assessors verify compliance with criteria is explained

The following table details how LEED and BREEAM score various categories and criteria.

LEED Scoring categories

40-49 points	50-59 points	60-79 points	80+ points
Certified	Silver	Gold	Platinum

BREEAM Scoring categories

30 <	= 30 30 >	> 45	> 55	> 70	> 85
Unclassified	Pass	Good	Very Good	Excellent	Outstanding

Before the retrofit, the 1983 office block had a zero-star energy rating.

385 Bourke St (Melbourne)

The 45-storey tower at 385 Bourke St, completed in 1983, is made of steel and concrete. It houses a variety of retail stores, a large food court, a number of other commercial tenants and the Melbourne headquarters of the Commonwealth Bank of Australia.

Snapshot

Year built 1983

Location 385 Bourke St, Melbourne, VIC

Size (NLA) Retail 6,000m², Office 55,000m²

Tenancy 50 retail stores and 2 levels of carpark

Refurbishment 2009 – 2011

Project costs $2.5M

NABERS Energy Initial: 0.0, Target: 2.5, Current: 3.5

NABERS Water Current: 3.5, Target: 4.5

Key features
- Upgraded BMS
- Economy mode
- Lux meter sensors for lighting control
- T5 fluorescent lamps installed
- Variable fan speeds
- Quantum heat pump units installed
- Additional sub-metering
- Chilled water controls
- Active air quality measurements

Energy saving 41% cut in energy consumption (372 MJ/m2/p.a.)

Greenhouse saving 4680 tonnes CO_2/p.a.

Annual saving To be confirmed

The plan included an upgrade and reinvigoration of the building's HVAC system. Photo: Government of Victoria

In 2004, an audit revealed the building had a zero-star energy rating. With mechanical systems nearing the end of their life, consultancy Umow Lai conducted a comprehensive environmental performance audit and then suggested ways to improve the building's energy efficiency. In 2005, the building owners, together with Sustainability Victoria and project managers, agreed to retrofit the building.

First, the building was retrofitted with BMS, building controls were rationalised, new fan motors and energy metering of the chilled water system installed, air quality measurements taken, and after-hours operation and zone control were monitored. Next, the HVAC system, heating and cooling water systems, and other sub-metering and chilled water controls were upgraded.

Objectives:

- Significantly reduce the building's energy consumption and carbon emissions
- Achieve a 2.5 NABERS Energy rating

Features and Implementation:

The project was implemented over two and half years and included the following features:

Heating, Ventilation, and Air Conditioning

- HVAC and Direct Digital Control systems re-tuned and re-balanced
- Variable fan speed drives installed in each AHU
- System reprogrammed to 'economy mode' instead of using chiller plant
- All air handling ducts monitored; leaks sealed
- Chiller operation revised
- Variable speed drives installed and AHU logic changed for a more efficient operation of HVAC in after-hours mode. Cooling and heating zoned at individual floors and areas.
- BAS upgraded and synchronised with central plant controls

Lighting and energy load

- Lux meter sensors installed and programmed to detect levels of ambient sunlight
- Smart controls including proximity sensors installed throughout the building
- Lighting upgraded with T5s energy efficient lamps

Environment

- Air handling systems installed to measure, respond to and prevent high levels of CO_2
- Air curtains on entrances replaced with automatic doors to increase savings in heating and cooling in food court and retail areas
- Low volatile organic compound carpet, paints and materials used

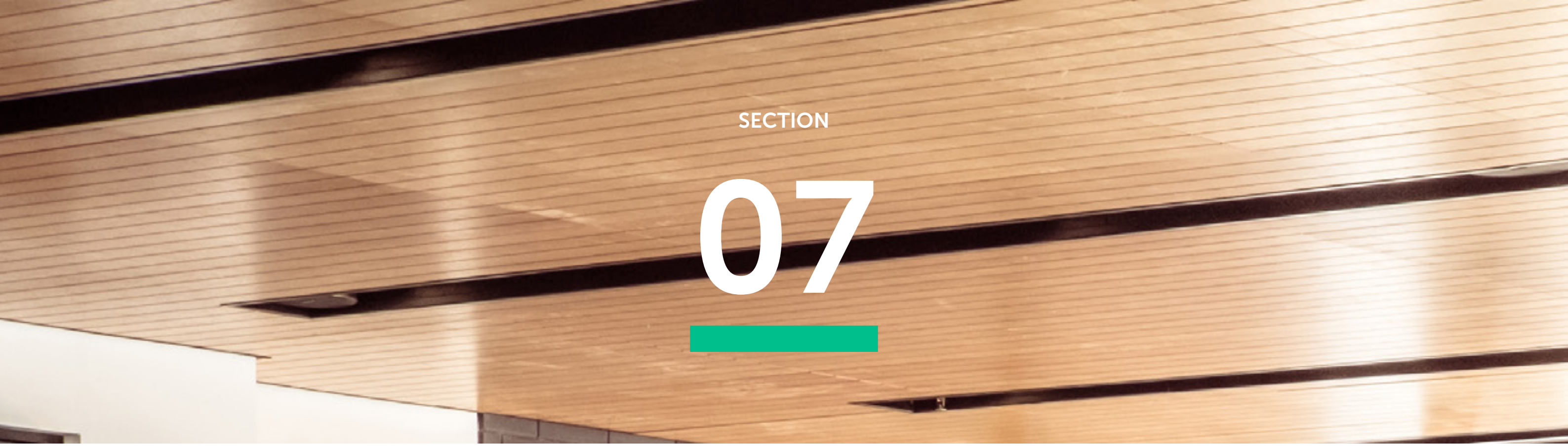
Building management and controls

- Energy metering implemented to improve monitoring and control of areas
- BMS fine-tuned to improve energy efficiency and building performance
- Sensors for system pressure and supply of air temperature recalibrated and relocated to increase accuracy and reliability

Outcomes:

- A 5.0 NABERS Energy rating equating to a 50% cut in energy consumption (5Mwh/p.a.)
- A 46% cut in CO_2 emissions (4,500 tonnes) p.a.
- Electricity savings of $460,000 p.a.

Read more at: melbourne.vic.gov.au



SECTION

07

Conclusion

Low carbon retrofitting presents a challenge and an opportunity for all stakeholders in the commercial built environment.

Commercial buildings are complex energy systems, with high and varying requirements from tenants who often have different operational patterns. Developers, owners and managers can all have conflicting priorities, too.

On top of that, it can be difficult to manage large buildings when stakeholders use different criteria to evaluate any new investment in the building.

But here in lies the opportunity: refurbishment of large commercial buildings can have a significant impact on the drive towards a low carbon economy, many tenants are willing to pay a premium to lease space in a sustainable building, and many owners have enough capital to undertake a refurbishment.

Low carbon refurbishment is also becoming easier and cheaper thanks to new and emerging technologies, everything from high-performing thermal insulation and advanced glazing to increasingly efficient HVAC systems and intelligent automation.

Bridging the gap between sustainability goals and the present state of commercial buildings is a complex problem which calls for an integrated strategy. We can start that process by assessing the return on investment, improved marketability and social benefits associated with lower-carbon refurbishments.

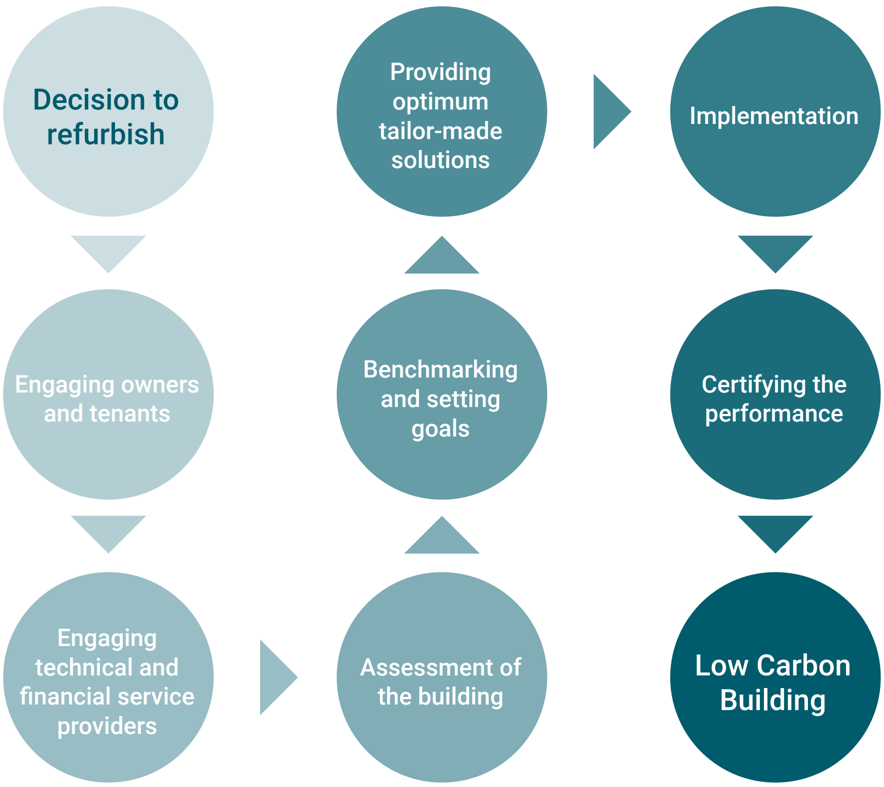


Figure 7.1 The path towards low carbon commercial buildings.

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