Sealing your home

Sealing your home against air leakage is one of the simplest upgrades you can undertake to increase your comfort while reducing your energy bills and carbon emissions by up to 25%.

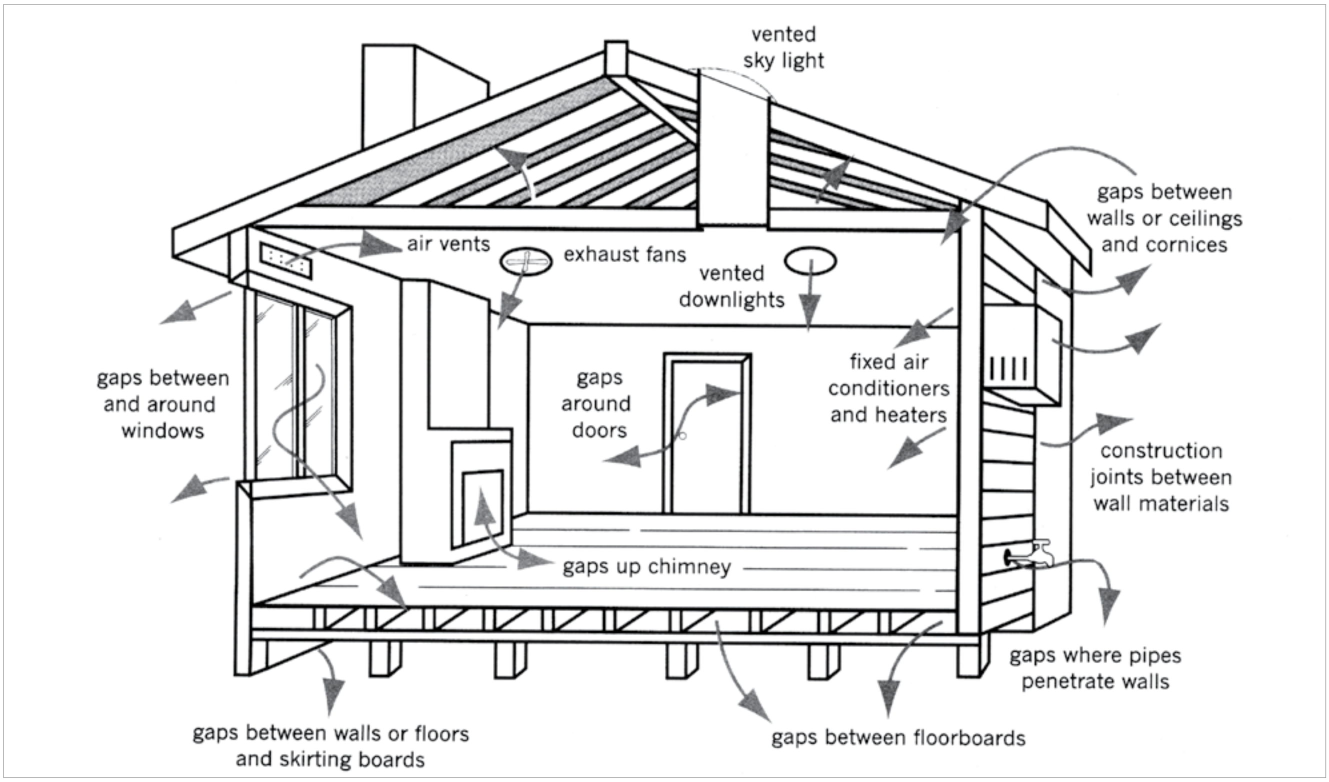
Air leakage accounts for 15–25% of winter heat loss in buildings and can contribute to a significant loss of coolness in climates where air conditioners are used. Tight sealing and increased insulation levels, however, can also create problems with condensation and indoor air quality. Understanding how condensation works and in which climates it is more likely to occur helps you limit its impact.

Air typically leaks through:

- unsealed or poorly sealed doors and windows
- the poor design or omission of airlocks
- unsealed vents, skylights and exhaust fans
- gaps in or around ceiling insulation and around ceiling penetrations (e.g. downlights, pipes and cables)
- gaps around wall penetrations (e.g. pipes, conduits, power outlets, switches, air conditioners and heaters)
- gaps between envelope element junctions (e.g. floor–wall or wall–ceiling)
- poorly fitted or shrunken floorboards.

Gaps in insulation and thermal bridging are also a substantial source of heat loss and can cause both draughts and condensation. These issues are discussed in *Passive solar heating*, *Insulation* and *Insulation installation*.

Any air leak in the building envelope of a solar-heated home compromises comfort and efficiency.

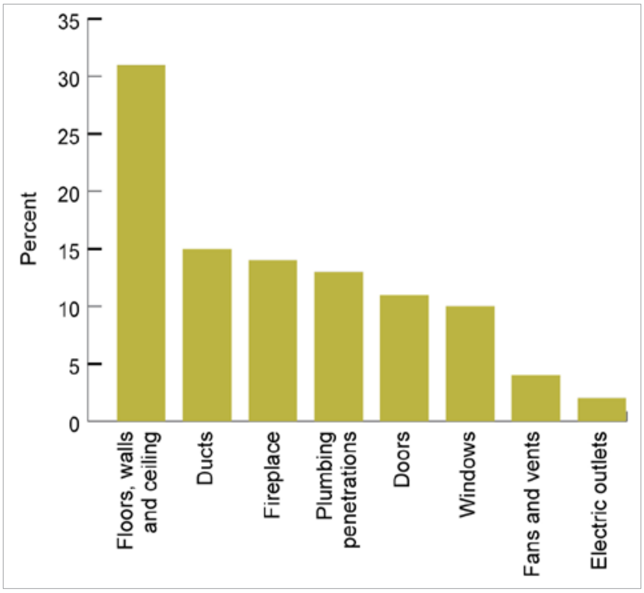


Source: SEAV

Common leakage points.

Sealing your home

All homes should be sealable if external air temperatures are beyond human thermal comfort levels for more than a few hours. How well sealed a home needs to be is largely determined by climate and varies substantially throughout Australia. (see *Insulation*)



Source: SEAV

Main sources of air leakage in a typical cool or cold climate home.

National building regulations (Building Code of Australia) have mandated minimum thermal comfort levels since 2003 and have generally led to improvement in the level of sealing in new homes. However, standards of air tightness are not mandated nor tested and certified even though additional sealing can deliver cost effective results in most climates, particularly in Zones 7 and 8 where heating is required for up to eight months of the year or Zones 1 and 2 where significant cooling is used.

The best time to air seal your home is during construction or renovation.

The vast majority of Australian houses would benefit from improved air sealing.

Measuring air tightness and infiltration rates

The air tightness of a building is usually measured using a pressure difference of 50 pascals (Pa) between inside and out, called the ACH_{50} value. The number of air changes per hour is then recorded and can be used to compare different buildings. However, a 50Pa pressure differential is quite low compared to typical wind pressures so also consider site specific conditions.

The table indicates air change rates that can be expected with a range of ratings, typical energy use related to heating or cooling of incoming air, and likely savings. The cost and saving figures are indicative only and vary depending on incoming air temperature, climate, wind exposure, the home's design, and the efficiency of its heating, ventilation and air conditioning systems.

Air tightness

ACH_{50}	Natural air change/hr	Ranking	% of cost	Potential saving from improved air sealing	Ventilation requirements
0.6	0.03	Aspirational Passivhaus*	1–2%*	No further sealing possible	Constant energy recovery ventilation
1.5	0.075	Best practice	2%	None: leakage costs minimal	Constant energy recovery ventilation
3.5	0.18	Excellent	6%	1–3%	Occasional forced ventilation
5	0.25	Better	10%	2–4%	Occasional
7	0.35	Good	14%	2–5%	Small
10	0.50	Fair	20%	3–10%	Rare
20	1.0	Poor	40%	5–10%	None — open vented

* Additional cost reductions for Passivhaus standard only achievable in extremely cold (not Australian) climates. NOTE: 'Passivhaus' is a concept developed for Germany's climates to assure the highest level of thermal comfort with minimal energy input. It applies all of the principles described in *Your Home* to the highest standard and is often referred to as a best practice benchmark for thermal performance, including air sealing.
Source: Energy Leaks Pty Ltd

Detecting leaks

In milder climates, the DIY approach is often adequate, but in colder climates, where higher levels of sealing are beneficial, taking the time to thoroughly identify and accurately measure air leakage usually more than pays for itself.

Before starting, consider the contribution of different types of leaks to help prioritise your sealing schedule. Leakage through a hole or gap in the building envelope varies with the shape; for example, a long thin crack responds less to variations in air pressure than a round hole. Ceiling level leaks lose more heat than floor level leaks due to the stratification of warm air. Cold air entering near floor level creates discomfort and potentially confuses heater thermostats.

DIY detection

Many air leakage sources are obvious but you must identify the less obvious gaps to properly seal your home. DIY air sealing is a progressive activity that usually starts with the larger, more obvious leaks and gradually attends to smaller, less obvious ones.

Step 1: Identify and seal all obvious gaps

- under doors
- mail delivery and cat flaps
- around doors and window frames, especially behind architraves
- fixed vents and wet area window ventilators
- gaps between floorboards
- chimneys
- vented skylights
- air conditioners, especially evaporative coolers
- dryer vents
- downlights
- exhaust fans
- large cracks
- gaps above built-in wardrobes
- services entry points (plumbing, drainage, gas, electricity, phone and TV cables)
- joints where materials meet (especially dissimilar ones and floor–wall, wall–ceiling)
- holes in heating or cooling ducts

After attending to each of these, you should have substantially improved the air tightness of your home and are ready for Step 2.

Step 2: Depressurise your home

- Choose a cool, very windy day (or a hot day in climates requiring cooling).
- Shut all windows and doors and turn off any ducted heating, cooling or ventilation systems that blow air into the house.
- Turn on all fans that suck air outside, such as exhaust fans and range hoods.
- Consider placing a fan in a window to suck air out (seal around it with masking tape and cardboard).
- Light an incense stick and pass it around the edges of all common leak sites. Wherever the smoke is blown back into the room, there's an air leak.

After sealing the leaks identified in this step, the air tightness of your home is probably above average.

Step 3: Pressurise your home

- Choose a cool, still day.
- Shut all windows and doors and turn off all fans that suck air outside.
- Turn on all ducted heating, cooling or ventilation systems that blow air into the house.
- Consider sealing a fan in a window to blow air into the house.
- Use an incense stick to detect air movement and follow it to the exit point; this can be difficult to find quickly, so work methodically. If the exit point is an exhaust fan or duct, it requires self-closing baffles. Temporarily seal these with paper and masking tape and continue.
- Other points of leakage then need permanent fixing, such as sealing behind architraves or under floorboards.

After sealing every outgoing leak you can find, you have probably achieved adequate air tightness for your home to perform efficiently in most Australian climates.

Step 4: Thermal imaging

Consider examining the outside of the home with a thermal imaging camera. These are reasonably inexpensive to hire, and many digital cameras have thermal imaging capacity already built in.

- Choose a cold day or evening (or hot if you are in a hot climate).
- Turn your thermostat or heater to the highest setting (coldest for cooling) and allow the house to achieve maximum (or minimum) temperature.
- Pressurise the home as in Step 3 above.

- Carefully examine the exterior through the thermal imaging lens to detect sources of heat loss (or cool air loss). Some of these will be air leaks, others insulation leaks and thermal bridging. (Note how much heat escapes through glass in closed windows.) In particular, check:
  - roof junctions — ridges, hips, eaves, gables and penetrations, especially skylights
  - external vents and cowlings
  - windows and doors, looking separately at the frames and glazing, and the sealing of the frame to the wall
  - wall–eaves junctions
  - corners and joins between materials.

Photograph all thermal bridging points and consult a professional designer or energy rater to analyse their cause and discuss ways to minimise them — the thermal images will undoubtedly have identified heat loss sources that go well beyond air leaks. (see *Insulation*; *Insulation installation*; *Glazing*)

Thermal imaging can also be used inside to identify air leakage and other issues such as standby power usage (i.e. detecting heat coming from appliances and equipment that are not in operation).

Professional inspection

Qualified technicians can conduct air leak audits and suggest solutions for problem areas. Some companies offer a full retrofit building sealing service. Blower door tests are used to measure the air tightness of the building and thermal imaging cameras locate the leaks.

A more detailed energy assessment can also be obtained where, in addition to an air leak audit, the technician examines all aspects of your home's thermal performance. This includes glazing, insulation, thermal bridging, thermal mass, air tightness, and passive heating and cooling. These reports are more simply understood when explained through thermal images.

Sealing air leaks

Air leaks are year-round issues: in winter, they allow valuable hot air to escape and unwanted external cold air to enter; in summer, the reverse occurs.

Usually the most cost effective solution is to start sealing the largest and most obvious leaks, and then move to significant cracks and penetrations. When these are sealed, smaller leakages become more obvious (and significant in high winds) using the detection methods above. Because large leaks in roof spaces may be difficult to locate and seal, professional advice may be required.

Blower door tests

Blower door testing is a diagnostic tool designed to measure the air tightness of buildings. It uses a calibrated fan capable of measuring airflow, mounted in a flexible panel positioned in an external door.

A pressure-sensing device measures the air pressure created by the fan. The fan both pressurises and depressurises the home. By recording both flow and pressure in each direction, the system is able to provide highly detailed information about building air tightness.

The data is normalised for the size of the building to allow comparison of various sized buildings using the air tightness metric ACH_{50} explained above.

Building envelope

Use airtight construction detailing, particularly at wall–ceiling and wall–floor junctions. Standard cornices set with cornice cement achieve this while allowing for building movement. Traditional quads and timber moldings do not, unless joints are filled with sealant before fixing.

Design to control ventilation so it occurs when and where you want it. In cooler climates, the use of openable windows for ventilation is increasingly under review. Designers are now considering fixed sealed glass for light, views and solar gains, and purpose-designed sealable wall and floor vents in strategic locations for ventilation. In warmer climates openable windows with good air seals are the preferred option.

Seal junctions and gaps between building components with durable, flexible caulks and seals:

- at the junction of window and door frames, walls, floors and ceilings, skirting boards, plumbing pipes, exposed rafters and beams, inbuilt heaters and air conditioners
- between dissimilar materials (e.g. masonry walls and timber framing).

In cavity wall construction, internal sealing is more effective.

Seal larger gaps with expandable foam.

Provide airlocks at all external openings. Design door swings so that they blow closed — not open. Airlocks can be double purpose rooms (e.g. laundries and mud rooms). Seal wood storage areas if wood heating is used.

Avoid using cavity sliding doors in air leak paths because they are hard to seal.

Seal gaps between the window and door frames and the structural building frame before fitting architraves. Cavity construction (e.g. brick veneer) requires that cavities be ventilated to prevent mould growth. In windy conditions, cavities become pressurised and leak if not sealed.

While sarking membranes can prevent air from entering around wall penetrations such as switches and power points, there is usually a gap left around windows. When architraves are fitted, they often don't create a good seal. This allows cavity air to enter under pressure.

This gap should be sealed by:

- taping the sarking to the frame
- using expanding foam (take care not to bow the reveals)
- pushing strips of bulk insulation into the gaps around the frame.

Use tight fitting flooring and insulate the underside of raised floors with airtight, insulative membranes in cooler climates. Various insulating sheet and roll membranes are available and simply installed. Tape joins and seal to the edge to prevent penetration by air pressure from subfloor vents. Do not block vents or wall cavities.

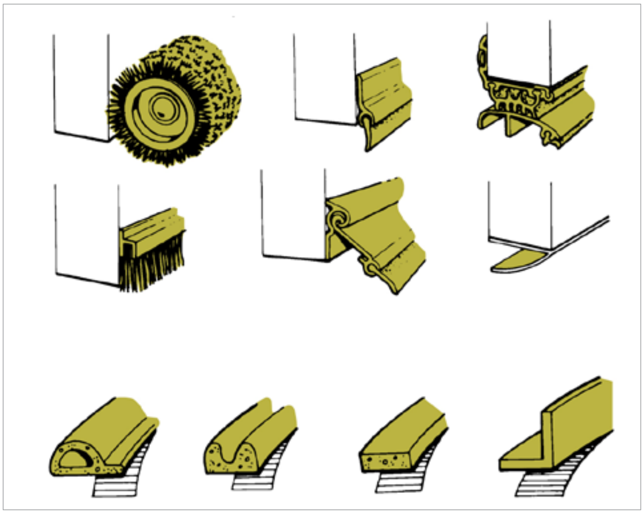
Windows and doors

Choose well made windows and doors with tight air seals. Many manufacturers exceed the minimum standard many times over with air infiltration rates of 0.7L/s.m^2 or better. Australian Standard AS2047, Windows in buildings — selection and installation, allows a maximum infiltration rate of 5.0L/s.m^2 at a positive pressure difference of 75Pa but this is inadequate in cool and cold climates, particularly in high wind areas. Window manufacturers are required to have their products tested to this standard and register them with the Windows Energy Rating Scheme (WERS).

Improve the performance of existing windows and doors by using proprietary draught-proofing strips, ensuring they are appropriate for the window style, i.e. maintain easy operation. Fit retractable draught seals at the bottom of hinged doors.

Overlapping brush seals can allow full movement of sliding or double hung windows while making an excellent seal. Self-adhesive neoprene pillow or foam strip seals are effective on hinged doors and casement and awning windows.

Fit automatic door closers to external doors and doors leading to unheated areas.



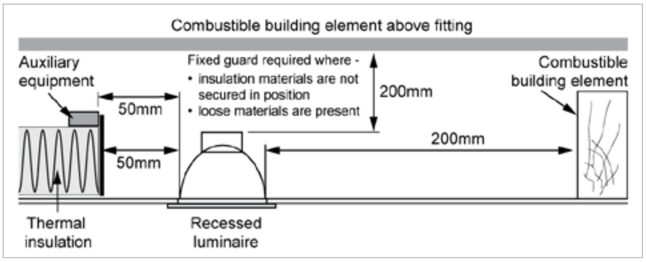
Many products are available for draught proofing.

Vents and penetrations

Avoid or replace open-vented downlights that penetrate ceiling insulation. In some situations you can replace in-ceiling downlights with downlights or uplights mounted on trapeze wires tensioned across the room at ceiling level, thereby avoiding all penetrations.

Lighting that emits high levels of heat (e.g. halogen) requires clear space around it so it does not come in contact with the roof structure or insulation (see *Lighting*). Proprietary heat-resistant isolation boxes are available but often cost as much as CFL or LED replacement lamps and can be difficult to fit. Choose sealed replacement lamps and ensure that insulation is kept clear of the lamp.

Flexible, sealed downlight covers are available.



Source: Adapted from AS/NZS 3000:2007 Figure 4.7 — reproduced with permission from SAI Global

Default minimum clearance for recessed lights.

Electrical outlets (switches and power points) are a common and particularly problematic source of leaks. They can be difficult to trace because construction air spaces become pressurised under wind loads and transfer draughts long distances from the source. This is especially a problem in cavity construction.

Sealing around switches and power points can help but this makes them difficult to remove for maintenance. Draught-proof building wraps in cavities or under cladding are ideal but are difficult to retrofit unless recladding. Wraps should also be breathable to avoid dew-point formation.

Breathable wraps allow some infiltration under wind pressure but, when combined with snug fitted bulk insulation, provide the best solution. Where this is unachievable, a qualified electrician may be able to fit self-adhesive seals to the back of plates or seal problematic outlets with spray foam injected into the air space.

Duct exhaust fans to outside and install non-return baffles. Exhaust fans and range hoods commonly open into the roof space, allowing uncontrolled movement of air. This raises water vapour levels and fire risk — see 'Condensation' and 'Ventilation' below.

Do not use permanently ventilated skylights. These allow hot air to escape and cold air to enter. Use a diffuser at ceiling level and a separate ducted exhaust fan with self-closing baffles.

Seal off permanent air vents. Use windows and doors or heat recovery systems for ventilation as required by climate.

Insulate manholes or roof space access hatches (which are often poorly sealed and uninsulated) with rigid insulation fixed to the hatch. Fit air seals to all sides.

Heating and cooling appliances

Unflued gas heaters require fixed ventilation to prevent the build-up of toxic gas. Mechanical systems can provide adequate ventilation but fail in blackouts when gas heaters continue to operate. Use ducted gas heaters or power flued or balanced flue space heaters that draw combustion air from outside and exhaust the flue gases without their coming into contact with the indoor air.

Open fireplaces should be avoided: they are inefficient and draw in large volumes of cold air to fuel combustion (see *Heating and cooling*). Fit dampers to occasionally used chimneys and flues and ensure that they are closed when not in use. Insulation regulations in Victoria require dampers to be fitted to all new fireplaces.

Heating and cooling duct penetrations through ceilings and floors are a common source of air leaks. Floor registers should be sealed with spray foam, compressed bulk insulation or self-adhesive sealing strips. Ceiling registers are generally not airtight and are often displaced during cleaning; seal with self-adhesive sealing strips.

Evaporative coolers often lack automatic dampers and therefore extract air from the house when they are not running, increasing heating bills and allowing outdoor heat to enter.

Avoiding condensation from air sealing

Increased insulation improves thermal comfort and energy efficiency, but air tightness in homes can have adverse consequences.

The risk of mould, mildew and decay rises with increased condensation as water vapour exits through building elements rather than air leaks. Water vapour generated by household activities (e.g. clothes drying, cooking, washing, showering) should be removed at source by externally vented, self-closing extractor fans.

The build-up of gases, toxins and pollutants resulting from reduced ventilation can trigger respiratory health issues. Toxic substances include:

- volatile organic compounds (VOCs) and formaldehyde emissions from furniture, carpet, finishes and building materials
- carbon monoxide, sulphur dioxide and nitrogen oxide from heating and cooking
- airborne toxins from household cleaners
- pollen, dust and dust mites.

To combat these problems, provide alternative ventilation (e.g. heat recovery ventilation systems) and well-designed vapour barriers that allow water vapour to escape before condensing. Detailed solutions to each are outlined below.

Condensation or dew-point formation

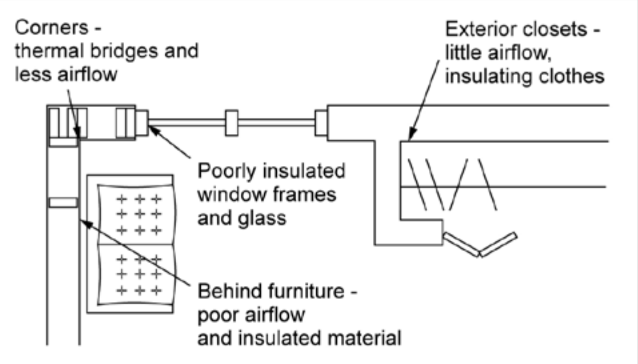
Water vapour in the air (humidity) condenses to its liquid state when cooled to a particular temperature — the dew-point temperature. There are two main types of condensation: surface and interstitial.

Increasing the air tightness of a home generally increases temperature and humidity differentials and increases interstitial condensation risk.

Surface condensation — occurs on any surface that is below the dew-point temperature of the air. Dew-point temperature varies according to the combined interaction of humidity, temperature and barometric pressure, calculated using a psychrometric chart.

Surface condensation can be minimised by:

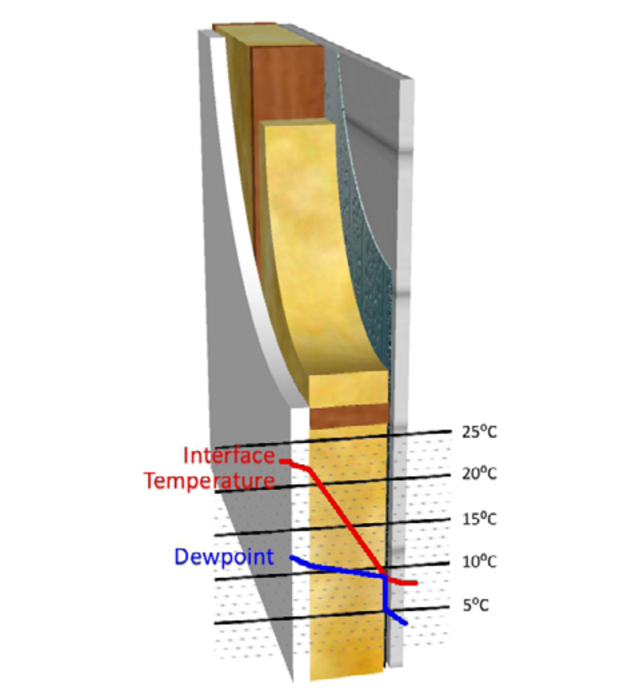
- installing heat recovery ventilation systems that dehumidify air
- reducing internal humidity levels by venting common sources to the outside (e.g. showers, clothes dryers, stoves, gas heaters)
- using insulation to maintain internal surface temperatures above dew-point; double glazing helps significantly for windows
- zoning heating areas to limit convection and temperature differentials in the house
- ensuring warm air circulates behind large furnishings on high risk external wall surfaces (e.g. south-facing or uninsulated walls, corners where thermal bridging occurs).



Source: Ontario Association of Architects.

Areas where mould is likely to form.

Interstitial condensation — results from the movement of water vapour through permeable building materials via diffusion, conduction and air movement, travelling from the high vapour pressure to the low vapour pressure side until it is either released by evaporation or condenses on a surface with a temperature below the dew-point. Such surfaces often occur within the wall, where dew-point formation or condensation can be highly problematic. Climate specific design responses are essential.



Water vapour condenses on any surface with a temperature below the dew-point.

There are two simple steps you can take to minimise the risk of interstitial condensation:

- Limit water vapour entry by using vapour barriers on the source side.
- Make the envelope breathable so that water vapour passes through without striking a surface that is below the dew-point; this includes having vapour permeable membranes on the exit side.

To achieve this, we need to predict which way the water vapour is travelling. The temperature and humidity differential on either side of the element create high and low vapour pressure and these conditions vary with climate, site conditions, diurnal range and occupant lifestyle.

These facts provide a useful basis for decisions:

- Water vapour moves from high vapour pressure to low vapour pressure, which is not always the same direction as air pressure.
- In cold climates where relative humidity is generally low and internal vapour levels high due to building sealing, the flow is typically from inside to outside.
- In hot humid climates movement is generally from outside to inside (except where night sky cooling of the roofing creates a dew-point).
- In mixed or temperate climates diffusion can work in either direction but is not always a condensation risk.

Building membranes — vapour barriers and breathable linings — are essential and are of three main types:

- vapour barriers that restrict the transmission of water vapour (e.g. non-perforated reflective foil insulation)
- vapour permeable (breathable) membranes that allow vapour to pass through (e.g. commonly used breathable building wraps, although many are only slightly permeable)
- smart membranes with vapour permeability that varies with temperature and humidity; various proprietary brands are available.

Permeability is measured as vapour resistance (a material's reluctance to let water vapour pass through) and usually expressed in meganewton seconds per gram (MNs/g). Membrane products are tested and rated according to AS/NZS 4200, Pliable building membranes and underlays. The lower the MNs/g rating, the more permeable the material.

Many perforated reflective foil insulation products have very low permeability (>7MNs/g) but are marketed as being permeable. Many building wraps are highly permeable (0.5MNs/g) but offer no reflective or low emissivity insulation benefits. Choose and correctly position membranes appropriate for each purpose and location.

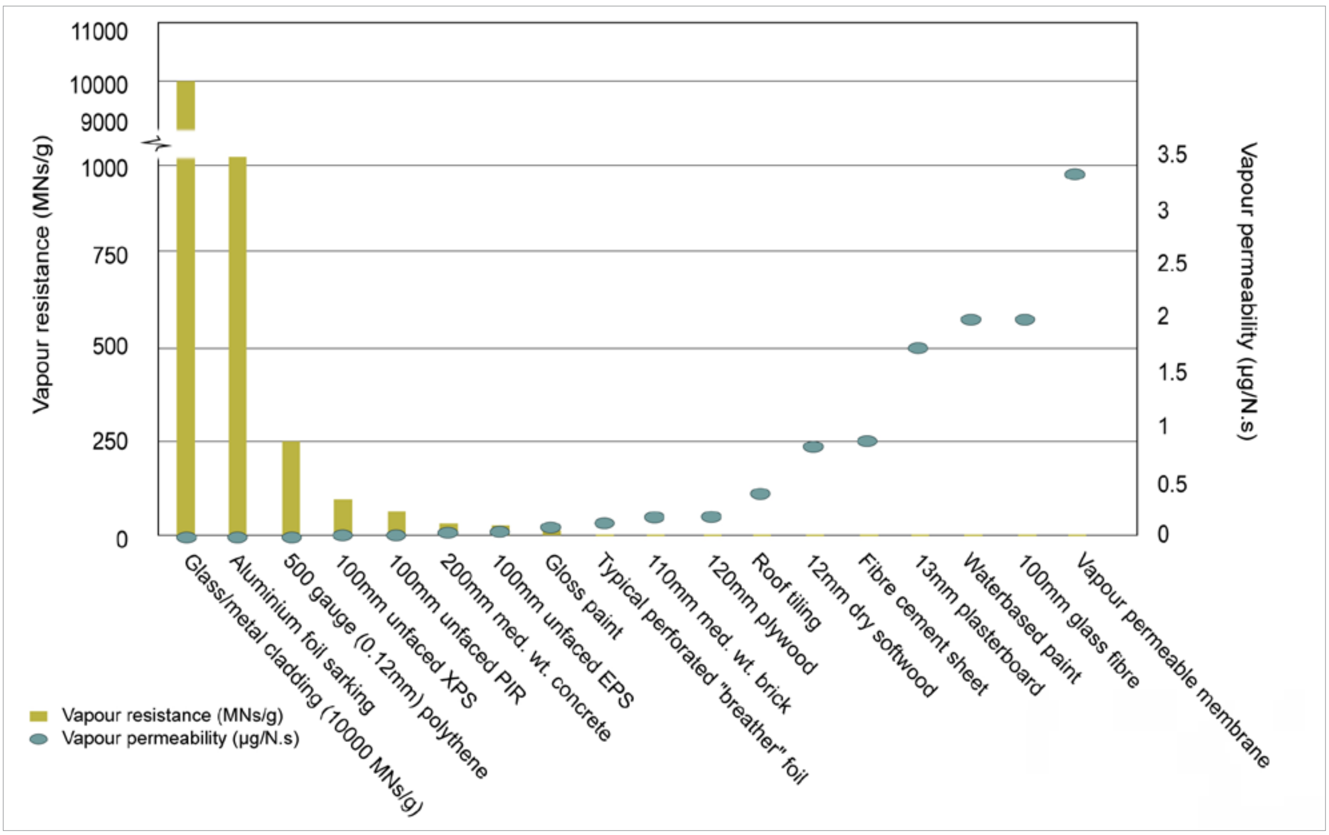
Breathable membranes should be placed on the cold side of insulation to allow vapour to escape before encountering a dew-point.

Smart membranes can be highly effective where cold and warm sides are interchangeable.

Correctly placed reflective vapour barriers prevent water vapour from reaching a dew-point surface. Always place them on the warm (vapour entry) side of the structure.

Vapour barriers on the lower side of the roofing material are also useful if they can be kept above dew-point. Otherwise, they should be permeable to water vapour but capable of directing any condensation that forms on the underside of the roofing clear of any structure. In cold climates, an additional vapour barrier or layer of reflective foil insulation should be placed just above the ceiling.

In cold climates such as Zones 7 and 8 where high levels of air sealing are most beneficial, water vapour usually moves outward because outside temperatures are generally lower than inside. The likelihood of outward movement increases as the weather becomes colder: even though external humidity is generally lower, internal humidity rises as occupants spend more time indoors,



Source: Russell 2011

Vapour permeability and resistance of typical materials.

taking longer and hotter showers, and using mechanical clothes dryers or drying racks in front of heaters.

Building membranes installed on the cold external side of insulation must therefore be breathable and designed to drain condensation away from building elements when dew-points form (see *Cladding*). Membranes on the warm internal side of the insulation should provide a vapour barrier to prevent warm moist internal air diffusing through the wall (ABCB 2011).

In temperate climates lower internal–external temperature and humidity differentials often reduce condensation risk but do not eliminate it. Typically, external surfaces exposed to winter sun and cooler summer internal surfaces mean that internal surfaces are cooler during the day and external surfaces are cooler at night.

Water vapour movement can be in either direction depending on seasonal and diurnal fluctuations. External membranes should be breathable and internal membranes, if installed, should prevent vapour entry (ABCB 2011).

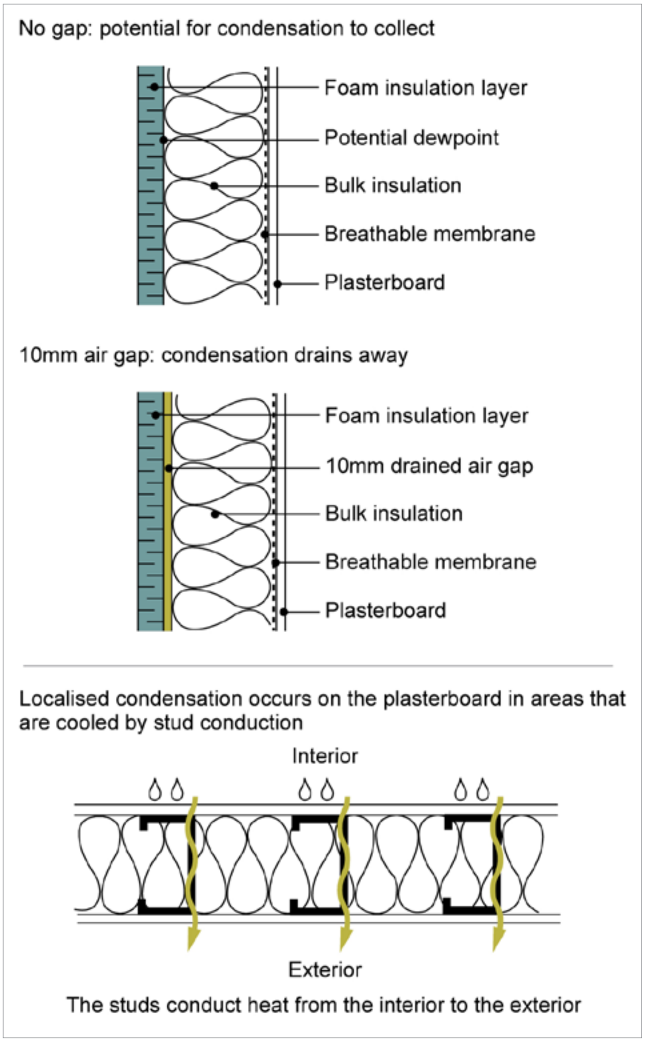
In tropical climates surface temperature conditions are similar to those of temperate climates except that external surfaces are rarely cooler at night and humidity levels are consistently higher.

An exception occurs where roof surfaces cooled by radiation to the night sky create temperature differentials, resulting in significant condensation on the underside of exposed impermeable surfaces such as metal roofing. The solution is a correctly detailed permeable membrane designed to drain condensation clear of building elements without leaking.

Membrane failure, faulty installation or incorrect detailing can lead to problem leaks that are not readily detectable.

Foil-faced insulation blankets with the foil facing upward can reduce temperature differentials and condensation but restrict building cooling through the one-way insulation valve effect (see *Insulation*; *Passive cooling*).

Where the building is consistently cooled, internal lining temperatures may drop below the dew-point of moist external air diffusing through external linings, causing internal condensation. In this case, dew-point forming vapour barriers should be located towards the outer layers of the wall and designed to drain condensation away from building elements (ABCB 2011)



Dew-point formation, interior and exterior walls.

Ventilation systems

There are many types of heating, ventilation and cooling systems offering various levels of dehumidification, filtering, heat recovery and choice of fresh air source. Their primary function is to supply sufficient fresh air to maintain indoor air quality but other options need to be addressed when choosing a system.

Consider the following:

- Is the roof space ventilated or sealed? (see *Passive solar heating*; *Passive cooling*)
- Does the system recover heat from outgoing air in winter?
- Is the system suited to a sealed envelope or does it rely on air leaks to exhaust stale air?

- Does the system rely on ceiling leakage as a return air path or roof space leakage as a source of fresh incoming air?
- Does the climate contribute to condensation problems?
- Do household lifestyles create high levels of water vapour and can these be exhausted clear of the roof space?
- Will the release of humid exhaust air into the roof space increase condensation risk?
- Is the roof space contaminated with toxic materials, dust or particles (e.g. asbestos or old insulation fibres)?

Appropriately chosen, designed and installed systems should:

- adjust the temperature and humidity levels of fresh air supply cost effectively to improve thermal comfort
- operate efficiently in a well-sealed home and roof space
- recover heat from outgoing stale air and use it to heat incoming fresh air
- allow seasonally responsive management of fresh air supply and ventilation rates to minimise energy consumption
- reduce the size, cost, running times and energy use of heating and cooling appliances
- comply with health and amenity standards including those in the 2011 ABCB handbook, Condensation in buildings.

Positive air replacement systems

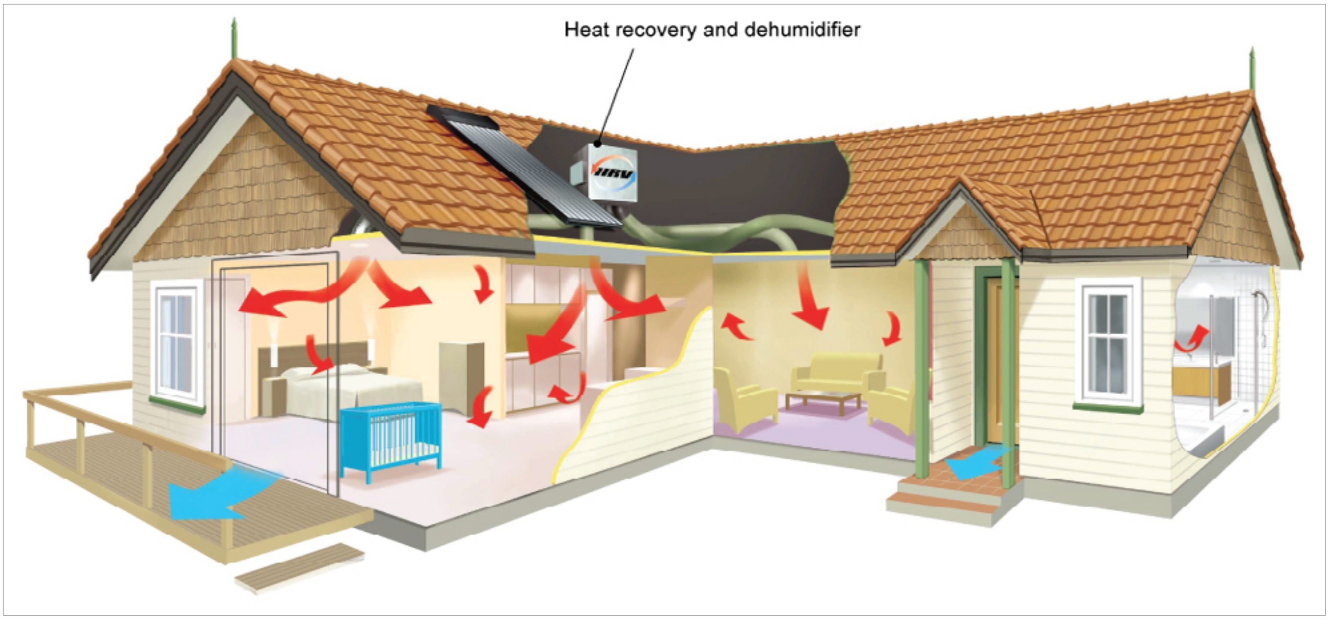
Positive pressure ventilation systems draw fresh air (usually dryer and cooler) from outside and feed it into the home under pressure through ducts. In its simplest form, this process forces moist stale air out through leaks and is not suitable for highly sealed homes unless special exhaust vents are fitted.

In some systems incoming air is not preheated or dehumidified, potentially leading to substantial heat loss in cooler climates and an increased risk of roof space condensation in all climates. These systems are most useful in mild or warm temperate climate homes that are poorly sealed, have limited natural ventilation and are in benign climates where the risk of roof space condensation is minimal.

More advanced systems offer options to draw air from a range of sources (e.g. roof space in winter, cool south-facing eaves in summer or isolated rooms where increased ventilation is beneficial). Heat recovery and humidity control can also be added. This is highly desirable in more extreme climates, for both heating and cooling.

Heat recovery systems

Heat recovery systems can provide a total ventilation system for well-sealed homes. They draw in fresh external air and extract heat from outgoing, humid air with heat pumps or heat exchangers and use it to heat fresh incoming air before returning it to selected rooms.



Source: HRV

Heat recovery systems.

These systems work in conjunction with your existing heating system and simply recover heat from outgoing air to minimise losses while maintaining fresh air replacement at levels required to maintain health and amenity.

Expert system design is recommended — there is significant potential for poorly designed systems to create unwanted side-effects.

Many heat recovery systems also dehumidify incoming air, reducing condensation risk. Some provide an option to draw warmer fresh air from the roof space in winter and filter it to remove pollutants before recirculating it.

Other systems rely on ceiling air leakage for return air supply or draw cooler external air into the roof space through vents, thereby increasing roof space condensation risk and reducing its role as a thermal buffer zone (see *Passive solar heating*). Flexible supply options are highly desirable.

Heat recovery systems that provide a controllable fresh air intake such as those used in Passivhaus applications are ideally suited to well-sealed homes in cool climates because they don't rely on air leakage to return or exhaust stale air as simpler configurations and positive displacement systems do.

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