Thermoregulation and air conditioning

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Research question:

What medical conditions or disabilities involve an impairment in thermoregulation?

What cooling systems are available for use in Australia?

Is air conditioning effective in managing symptoms of thermoregulation impairment compared to other cooling systems?

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1. Contents

2. Summary

Note: This paper is a substantial revision of a research paper originally completed in October 2019 and reviewed in February 2024.

Thermoregulation impairment can result from a wide range of health conditions and disabilities. The human thermoregulatory system involves perceptual, physiological and behavioural components. A condition may result in a thermoregulatory impairment if it affects the peripheral or central nervous systems, or if the condition impacts strength, mobility, motor control, cognition or emotional regulation.

The main types of cooling systems found in Australian homes are fans, evaporative and refrigerative air conditioners. Refrigerative air conditions, including reverse cycle air conditioners, are the most common type of air conditioner used in Australia. The cost-effectiveness of cooling systems depends on several factors including climate, location, energy prices, architectural features of the home, device running time, temperature set-point and other lifestyle factors.

There is evidence for the benefits of air conditioner use in the general population to manage the effects of heat, especially in very hot and dry climates. However, there is very little evidence comparing air conditioning with other cooling devices or strategies and very little experimental evidence showing the circumstances in which air conditioning might contribute to managing the symptoms of thermoregulation impairment.

Despite this, public health messaging and recommendations from researchers and clinicians are consistent. They suggest that simple behavioural strategies and easily accessible cooling devices have a role in managing the symptoms of thermoregulation impairment. Behavioural strategies include:

- understanding personal heat tolerance and preferences
- staying inside during the hotter times of day
- planning outdoor or strenuous activities for cooler times of day
- wearing loose or light clothing
- wearing wet clothes or wraps
- taking regular breaks from activity
- consuming cold foods and drinks
- taking cold baths or showers.

Recommended equipment or devices include:

- space coolers (including evaporative coolers and air conditioning)
- electric fans
- cooling garments.

3. Human thermoregulation

Humans are homeothermic animals, which means that human body temperature is maintained at a nearly constant level largely, but not entirely, independent of the environment. Core human body temperature is maintained at around 37°C (+/- 0.5°C), while peripheral body temperature may vary more widely (Romanovsky, 2018; Cheshire, 2016).

When the core body temperature is too low, this is called hypothermia. When the core body temperature is too high, this is called hyperthermia. Some sources refer to hypo and hyperthermia as any variation outside the normal range of core body temperature. (Romanovsky, 2018). Other sources define states more specifically as below 35°C for hypothermia and above 40°C for hyperthermia (Cheshire, 2016).

Slight changes outside the accepted range can be controlled with physiological or behavioural responses. Extreme changes to core body temperature may lead to significant injury or death (Osila et al, 2023; Cheshire, 2016). Age can affect the ability to regulate body temperature due to both physiological changes (such as changes in metabolism or the cardiovascular system) and behavioural changes (spending more time at home, reduced activity), which is why older people are more susceptible to complications from environmental extremes (Osila et al, 2023; Bennetts et al, 2020).

Thermoregulation is the process of maintaining body temperature by balancing heat generation and heat loss. Temperature variations are picked up by thermoreceptors on the skin or inside the body. These receptors alert the thermoregulatory centre located in the hypothalamus to enact thermoeffectors, physiological or behavioural responses that regulate body temperature.

3.1 Thermoeffectors

Physiological thermoeffectors are involuntary body processes that help to control heat loss or heat generation. They include:

- skin vasodilation or vasoconstriction
- sweating
- shivering
- piloerection
- panting.

Behavioural thermoeffectors are voluntary or instinctual complex behaviours. They include behaviours such as changing posture, drinking water, adding or removing clothing, turning on a fan or air conditioning etc (Osila et al, 2023; Romanovsky, 2018).

Thermoeffectors aid in heat loss, conservation or generation by affecting one or more of the four processes of heat exchange: conduction, convection, radiation, and evaporation (Osila et al, 2023; Romanovsky, 2018; Cheshire, 2016).

Conduction

Conduction occurs when heat is transferred from one object to another object in direct contact. Materials with high conductivity are more able to draw heat away from the body. For example, water has a high conductivity and so submersion in water is a good way to draw heat from the body (Osila et al, 2023; Romanovsky, 2018).

Convection

Convection occurs when a body is submerged in a gas or liquid. Movement of the fluid replaces layers of fluid closer to the body with fluid further from the body. The layers of fluid closer to the body have a temperature closer to the temperature of the skin, while the more distant fluid has a temperature closer to the ambient temperature. Convection therefore intensifies conduction. If the environment is hotter, the body is exposed to hotter material and so heats up faster. If the environment is colder, the body is exposed to colder material and so cools down faster. For example, a ceiling fan cools by convection by increasing movement of air on the skin, removing warmer air closer to the body and replacing it with cooler air further from body (Osila et al, 2023; Romanovsky, 2018).

Radiation

All materials emit and absorb heat via radiation in the form of electromagnetic waves. The human body loses approximately 60% of its heat via radiation. Unlike conduction or convection, radiation does not require contact with a medium. For example, solar radiation can warm the earth despite passing through colder layers of earth’s atmosphere (Osila et al, 2023; Connor, 2022; Romanovsky, 2018; Cheshire, 2016).

Evaporation

Liquid requires energy in the form of heat to evaporate. The heat required is drawn from the environment or from the liquid itself and transferred from the liquid to the gas. For example, animals make use of evaporative cooling in the form of sweating and panting (Osila et al, 2023; Romanovsky, 2018; Lohner, 2017). Evaporation accounts for about 22-30% of heat lost from the body (Osila et al, 2023; Cheshire, 2016). Evaporation is the most efficient form of heat loss in the human body, though it can be less effective in more humid environments and does consume large amounts of water. Evaporation is the only form of heat transfer that also works when the ambient temperature is higher than the temperature of the skin (Romanovsky, 2018).

4. Conditions resulting in thermoregulation impairment

Some conditions can impair our thermoregulatory processes and therefore increase the risk of temperature related health problems. The sections below describe some, though not all, conditions for which there is evidence of thermoregulatory impairment. For most conditions, whether thermoregulation impairment occurs, or whether the impairment is substantial and results in activity limitations or participation restrictions, will vary for individuals.

Conditions that affect the nervous system or skin (including brain and spinal cord injuries, severe burns, neuropathies, and neurodegenerative conditions) can impair physiological and behavioural thermoeffectors (Osila et al, 2023; Cheshire, 2016). Even when physiological thermoregulation processes are unaffected, some conditions can impair behavioural thermoeffectors, interrupting a person's capacity to voluntarily regulate their body temperature. For example, any condition that affects mobility may also reduce capacity for heat generation due to reduced or infrequent muscle contractions. Any condition that impairs judgement may also reduce a person's capacity to respond appropriately to changes in temperature (Cheshire, 2016). Refer to Table 1 for an incomplete list of conditions that may lead to or increase the risk of temperature related illness.

Conditions that result in thermoregulation impairment can significantly impact functional capacity and quality of life, though this is not always the case. These conditions may or may not result in activity limitations or participation restrictions in activities of daily living, social or economic participation. For example, there is evidence that most people with peripheral neuropathy experience anhidrosis or some level of impairment in their ability to sweat. However, only a quarter of those with this impairment will experience higher core body temperatures compared to the general population (Fealey, 2018). Therefore, the impairment to a thermoregulatory process (reduced ability to sweat) may not ultimately increase the risk of heat related illness or reduce the person's capacity to participate in any activity.

Table 1 Conditions that may contribute to thermoregulation impairment (Source: Cheshire, 2016)

Type	Condition
Conditions that may impair judgement	Dementia, head injury, schizophrenia, hepatic encephalopathy
Conditions that may impair mobility	Musculoskeletal injury, stroke, spinal cord injury, Parkinson's disease, multiple system atrophy, myopathy, severe peripheral neuropathy
Conditions that may impair thermal sensation	Peripheral neuropathy, severe burns
Conditions that may impair thermoregulatory responses	Wernicke encephalopathy, stroke, spinal cord injury, Guillain–Barré syndrome, amyotrophic lateral sclerosis, multiple sclerosis, myopathy
Conditions that may cause anhidrosis	Cholinergic neuropathy, autoimmune autonomic ganglionopathy, chronic idiopathic anhidrosis, botulism, generalized small fiber neuropathy,

	Sjögren syndrome, multiple system atrophy, Fabry's disease, bilateral cervical sympathectomy
Conditions that may increase thermogenesis	Status epilepticus, neuroleptic malignant syndrome, malignant hyperthermia
Other conditions that may lead to thermoregulatory impairment	Hypoglycemia, Diabetic ketoacidosis, Hypothyroidism, Adrenal failure, Hypopituitarism, Renal failure, Shock, Sepsis, Anorexia nervosa, Thyrotoxicosis, Pheochromocytoma

4.1 Spinal cord injury

There is evidence of impaired thermoregulation in people with spinal cord injury, mostly likely due to a combination of reduced activity of thermoreceptors to detect changes in temperature, reduced muscle mass and impairment in thermoeffectors such as sweating, vasoconstriction and vasodilation (Osila et al, 2023; Grossman et al, 2021; Zhang, 2019; Price & Trbovich, 2018; Cheshire, 2016; Girard, 2015). People with higher level of lesion show greater thermoregulatory impairment (Osila et al, 2023; Grossman et al, 2021). There is evidence that people with spinal cord injury below the level of T6 can regulate body temperature as effectively as people without spinal cord injury (Grossman et al, 2021; Price & Trbovich, 2018). There is some evidence that thermoregulation impairment in people with spinal cord injuries above T6 may also lead to activity limitations. For example, high or low temperatures may prevent people with tetraplegia from participating in activities outside the home (Price & Trbovich, 2018).

4.2 Acquired brain injury

Thermoregulatory impairment after brain injury (traumatic brain injury or stroke) may involve injury to the hypothalamus, changes in blood flow, vascular control and metabolism, and difficulties with mobility or judgement (Gowda et al, 2018; Cheshire, 2016; Thompson et al, 2003). There is evidence that around 70% of people experience hyperthermia during the acute phase after traumatic brain injury. This may be due to the nature of the injury, post-traumatic inflammation or post-injury infection (Thompson et al, 2003). Hyperthermia is a risk factor for secondary injury. This includes rebound hyperthermia, which is a possible consequence of rewarming after induced hypothermia (Gowda et al, 2018; Childs & Lunn, 2013). Clinicians regularly induce hypothermia soon after the initial brain injury to prevent secondary brain injury and improve other outcomes. Thermoregulatory impairment may be more common in some people with brain injury, though affected sub-groups have not been identified (Gowda et al, 2018).

4.3 Parkinson's Disease

Thermoregulation difficulties are common in people with Parkinson's disease and may lead to difficulties with sweating, sleep, and altered perception of heat and cold (Pfeiffer, 2020; Coon & Low, 2018; Zhong et al, 2013). The presence of peripheral neuropathy in people with Parkinson's disease can result in impairments to thermoeffectors such as vasoconstriction/dilation, sweating and piloerection (Coon & Low, 2018). Around 30-70% of people with Parkinson's experience problems with sweating, including hyperhidrosis (increased sweating) and hypohidrosis (reduced sweating). This may be related to neurological changes or to medications used to treat the core symptoms of Parkinson's disease. Hypohidrosis can increase risk of overheating, while hyperhidrosis can be uncomfortable and lead to sleep difficulties (Pfeiffer, 2020; Jost, 2017). Thermoregulation impairment can affect well-being and quality of life for people with Parkinson's disease:

> Patients are often bothered by heat intolerance which may influence activity levels and social endeavors. Needing to frequently change clothing or bedding due to excessive sweating episodes is also problematic for patients and their caregivers, particularly when motor function is compromised. Temperature intolerance or night sweats may impair a patient's sleep, which is often affected due to motor dysfunction or concomitant sleep disorders. Social function is also affected by sweating episodes, leaving some patients to feel embarrassed and contributing to social isolation (Coon & Law, 2018, p.271).

4.4 Multiple Sclerosis

Thermoregulation impairment is more researched in multiple sclerosis than for any other condition. Around 60-80% of people with multiple sclerosis experience temperature sensitivity. Thermoregulatory difficulties in people with multiple sclerosis, especially susceptibility to hyperthermia, may be due to impaired sweating function, decreased sensitivity of thermoreceptors or hypothalamic dysfunction. Hyperthermia is a significant risk as it can exacerbate symptoms including muscle weakness, spasticity, fatigue, blurred vision and pain, as well as worsening existing difficulties with balance, processing speed, concentration, and attention (Osila et al, 2023; Christogianni et al, 2022; Razi et al, 2022; Davis et al, 2018; Christogianni et al, 2018; Allen et al, 2017). Hyperthermia may be induced by environmental increases in temperature, hot baths or exercise (Razi et al, 2022; Christogianni et al, 2022; Davis et al, 2018; Christogianni et al, 2018). However, there is evidence that regular exercise for people with multiple sclerosis can improve symptoms and quality of life. Therefore, heat management strategies should be in place when clinicians recommend an exercise program for people with multiple sclerosis (Huang et al, 2015). Cold temperatures can also lead to a worsening of symptoms, though this is less common and less studied (Christogianni et al, 2018).

4.5 Peripheral neuropathy

Peripheral neuropathy is a general term for conditions that cause damage to the nerves of the peripheral nervous system. Damage can occur to large-diametre or small-diametre nerve fibres. Large fibres mediate motor and sensory functions, while small fibres mediate autonomic functions, pain and temperature (Novello & Pobre, 2023; Castelli et al, 2020).

Conditions that can result in peripheral neuropathy include Guillaine-Barre syndrome, diabetes mellitus, Fabry disease, Parkinson's disease, Ehlers Danlos syndrome, postural orthostatic tachycardia syndrome (POTS) and Sjögren syndrome. Diabetes related peripheral neuropathy is the most prevalent form of the peripheral neuropathy in developed countries (Osila et al, 2023; Fealey, 2018; Cheshire, 2016).

There is evidence that most people with some form of peripheral neuropathy experience abnormalities in core body temperature. Common thermoregulatory concerns for people with peripheral neuropathy include impairments to physiological thermoeffectors such as vasoconstriction/dilation, sweating, piloerection and shivering (Fealey, 2018; Cheshire, 2016). As peripheral neuropathy is associated with reduced sensitivity of thermoreceptors, there is also reason to believe the condition may lead to disruption of behavioural thermoeffectors (Fealey, 2018).

Heat intolerance is a possible symptom of POTS. High ambient temperatures may also exacerbate core symptom of orthostatic intolerance. (Fedorowski, 2018; Landero, 2014; Goodkin & Bellew, 2014). These symptoms may be associated with the presence of small fibre neuropathy. In a study of 276 participants with POTS, Angeli et al (2024) found 35% showed altered sweat patterns, which characterised the neuropathic phenotype. A small study of 30 people with POTS found significant differences in thermal perception and pain threshold (Billig et al, 2020). POTS is also a common co-occurring condition in Ehlers Danlos syndrome, which itself can present with thermoregulatory difficulties (Colman et al, 2023; Thwaites et al, 2022; Hakim et al, 2017).

4.6 Psychosocial conditions

While there is preliminary evidence that some people with anxiety disorders show abnormalities in physiological thermoeffectors such as vasodilation and sweating (Fischer et al, 2021), psychosocial conditions may coincide with thermoregulatory impairments in the form of altered sensation or disrupted behavioural thermoeffectors (due to altered cognition, judgement or executive control). RES 319 Weather and Bipolar Disorder contains some discussion of the effects of temperature on outcomes for people with bipolar and other psychosocial conditions.

4.7 Epilepsy and seizure disorders

Temperature may affect epilepsy and seizure activity differently, depending on the individual, the type of epilepsy or type of seizure.

Hyperthermia is both a possible trigger and a possible consequence of seizure. It may be a consequence of seizure due to excessive muscle activity or activation of the autonomic system (Pollandt & Bleck, 2018; Cheshire, 2016). Hyperthermia can also cause seizures, as in the case of febrile seizures experienced mainly by children during episodes of fever. In Dravet syndrome, seizures can follow even small temperature increases caused by higher ambient temperatures, fever, cold-warm shifts, warm baths or exercise (Gulcebi et al, 2021; Pollandt & Bleck, 2018).

However, colder temperatures may also increase risk of seizure in epilepsy. Hospital admission studies in Taiwan, Germany and Korea found that seizure risk increases in colder temperatures (Chang et al, 2019; Kim et al, 2017; Rakers et al, 2017). However, these studies take place in climates that tend to have mild summers and may not generalise to Australia. For example, Rakers et al (2017) found that ambient temperatures higher than 20°C decrease the risk of seizure, though the highest recorded temperature in the study was 28°C.

Epilepsy Action Australia (n.d.) states:

> Whilst research related to weather and seizures has been limited, and based in the northern hemisphere, there is no scientific evidence that hot weather itself causes seizures to occur in people with epilepsy. In Australia it appears most people report that the heat, or becoming overheated, tends to increase the likelihood of seizures. Becoming severely overheated can cause seizures, but an average hot day is not in itself the culprit.
>
> Obviously, heat can be a major contributor to dehydration. If someone is exposed to heat for a long period of time and does not drink enough fluid, this can cause dehydration which can increase the risk of a seizure in someone with epilepsy, sometimes later in the day. When fluid loss from the body (mostly perspiration) is greater than fluid intake, it causes a change in electrolytes – a drop in sodium (salt) and glucose (sugar) levels in the body. Ultimately, this can lead to low blood sugar levels (hypoglycemia) which can also trigger seizures for some people.

4.8 Autism

People with autism may experience sensory differences such as hypo or hypersensitivity to heat or cold (Raising Children Network, 2024; Zaniboni et al, 2023; Hidaka et al, 2023). Based on their review, Zaniboni et al suggest the following sensory differences with respect to perception of heat and cold:

- Different tactile sensitivity, as well as higher variability in warm and cold detection: paradoxical heat sensation (the perception of heat when it should not be perceived, hyper-sensitivity), lower thresholds in heat and cold detection (hypo-sensitivity).
- Thermal processing might be related with environment adoption or self-injury.
- Difficulties with interoception (heart-rate and body-temperature perception) and self-regulation and identification of emotions.
- Differences in hypothalamus development (related to homeostasic regulation, including metabolic rate, temperature and emotion). This can also lead to depression, anxiety, sleep disorders and obesity (2023, p.10).

4.9 Motor neurone disease / Amyotrophic lateral sclerosis

There is a lack of evidence regarding thermoregulatory impairments in motor neurone diseases such as amyotrophic lateral sclerosis (ALS). It is likely that behavioural thermoeffectors are impaired in ALS considering symptoms related to mobility and cognitive functions. There is minimal evidence that people with ALS experience altered heat sensation and that hypothalamus volume may be reduced. Physiological thermoeffectors such as shivering may be affected by progressive impairment in skeletal muscles (Dupuis et al, 2018). Much of the evidence for involvement of thermoregulatory systems in ALS comes from studies of animal models (Rodríguez-Sánchez et al, 2022; Braun et al, 2019). In their review of the subject, Dupuis et al state:

> In our clinical experience, we observed that ALS patients often complain of feeling hot, or conversely of being unable to warm up, and some patients develop low body temperature. Also, some patients report a worsening of symptoms in cold weather. However, these symptoms are generally not considered as being part of the core clinical picture, mostly because they are attributed to muscle atrophy and/or nerve degeneration. Therefore, potential thermoregulatory defects to the best of our knowledge have never been systematically studied in ALS patients (2018, p.750).

Since then, at least one study has shown a high rate of hypothermia in people with ALS who have had tracheostomy or invasive ventilation for longer than five years (Nakayama et al, 2018).

4.10 Huntington's disease

Thermoregulation problems are sometimes reported by people with Huntington's disease:

> some clinicians do occasionally report anecdotally that some of their [Huntington's disease] patients seem to have a striking indifference to cold and that they will dress too lightly for the weather, while others will sweat so profusely that they resort to wearing cooling vests (Weydt et al, 2018, p.766).

The first case study of a person with Huntington's disease presenting with hypothermia was submitted in 2020 (Altiner et al, 2020). Most of the evidence of thermoregulation impairment in

Huntington's disease comes from animal models. These studies have shown evidence of hypothermia, weight loss, involuntary movements, as well as differences in circadian rhythms, brown adipose tissue, skeletal muscle and the hypothalamus. This suggests a possible effect of Huntington's disease on heat retention, shivering and non-shivering thermogenesis. Development of psychiatric conditions and problems with mobility and cognitive function may also contribute to disruption of behavioural thermoeffectors. There are few studies directly investigating thermoregulation associated with Huntington's disease in humans (Altiner et al, 2020; Weydt et al, 2018).

4.11 Severe burns

The skin plays an important role in thermoregulatory processes including heat retention, sensation, sweating, piloerection, vasodilation and vasoconstriction. When large parts of the skin are lost or damaged, this enables increased heat loss and contributes to difficulties sensing changes in temperature, thereby increasing the risk of hypothermia. People with severe burns are also at risk of hypermetabolism, which can lead to hyperthermia, excessive sweating, weight loss, muscle wasting and other symptoms (Radzikowska-Büchner et al, 2023; Mertin et al, 2022). In cases of severe burn injury, metabolic changes can last up to three years after the initial injury and function of damaged skin may not return (Radzikowska-Büchner et al, 2023; Jeshke et al, 2011).

5. Management of thermoregulation impairment

Researchers and clinicians have recommended behavioural strategies to manage thermoregulation impairment in people with multiple sclerosis (Christogianni et al, 2022; Davis et al, 2018), autism (Zaniboni et al, 2023), and spinal cord injury (Girard, 2015). Behavioural strategies can include moving to a cooler area, planning activities for cooler times of the day, taking regular breaks from strenuous activity, choosing weather appropriate clothing, or gradual acclimatisation in warmer or colder temperatures (Healthdirect, 2024; Zaniboni et al, 2023; Grossman et al, 2021; Davis et al, 2018; Girard, 2015; Australian Red Cross, n.d.).

Standard first line treatment for hyperthermia includes cooling strategies that are usually low cost or readily accessible: air conditioning, misting fans, cold bath or shower, drinking cold water and applying cold packs or ice packs (Healthdirect, 2024; Grossman et al, 2021; Christogianni et al, 2022; Davis et al, 2018; Gowda et al, 2018; Hopkins et al, 2018; Zawardska et al, 2017; Cheshire, 2016; Australian Red Cross, n.d.). These non-invasive methods are less easy to control than invasive cooling strategies such as intravenous injection of cooling substances. Where non-invasive strategies succeed in lowering body temperature, they are not easily able to maintain a stable target temperature and therefore require monitoring and adjustment (Gowda et al, 2018).

There is evidence of effectiveness of non-invasive cooling strategies to improve exercise performance and lower the risk of heat related effects of exercise in the general population (Heydenreich et al, 2023; Douzi et al, 2019). There is mixed evidence for the effectiveness of non-invasive strategies in people with thermoregulatory impairment. The inconsistency in the evidence may be due to the frequency of small, low powered studies and the heterogeneity of climatic conditions and outcome measures (Grossman et al, 2021).

In a review of cooling strategies for people with spinal cord injury, Grossman et al (2021) found inconsistent evidence for the temperature reducing effects of cooling garments, cold drinks and misting fans. Some studies show cooling garments reduce skin temperature but not core body temperature, whereas a consistent effect across several studies showed pre-cooling using cooling garments or other methods could improve endurance during exercise and lower rate of increase of body temperature (Grossman et al, 2021; Davis et al, 2018).

A 2023 systematic review into the use of cooling garments for people with Multiple Sclerosis found that cooling garments are effective in reducing body temperature and improving walking capacity and functional mobility (Stevens et al, 2023). The authors found no significant differences between types of cooling garment. Active treatment groups were compared with either other cooling garments, sham active controls or passive controls. No study was reviewed that compared cooling garments with other cooling strategies such as air conditioning.

5.1 Air conditioning compared to other cooling strategies

Researchers and clinicians have recommended reducing the ambient temperature of the environment with space cooling strategies/devices as a way of managing thermoregulation impairment in people with multiple sclerosis (Christogianni et al, 2022; Davis et al, 2018), autism (Zaniboni et al, 2023), spinal cord injury (Price & Trbovich, 2018), epilepsy (Epilepsy Action Australia, n.d.), and severe burns (Radzikowska-Büchner et al, 2023).

Existing evidence indicates that air conditioning has a role in managing thermoregulation impairment. Hospital studies show air conditioning can improve or maintain patients' thermal comfort, recovery rates and well-being, and reduce infections and length of hospital stays. However, more research is required to determine the optimum ambient temperature to maximise patient outcomes (Lenzer et al, 2020; Shajahan et al, 2019). In the case of severe burns, raising the ambient temperature of the room to 24°C – 38°C may prevent or reduce the risk of a hypermetabolic reaction (Radzikowska-Büchner et al, 2023).

There are very few studies in which air conditioning is assessed as an intervention aimed to manage thermoregulation impairment. In a survey study of 438 heat-sensitive people with multiple sclerosis, Christogianni et al (2022) found that around three quarters used air conditioning to manage risks of overheating. However, in a review of cooling therapies/interventions for people with multiple sclerosis, Bilgin et al (2022) did not find any studies that used any conditioning as an intervention.

No studies were found comparing the use of air conditioning with other cooling methods in illness management or treatment. One study compared the use of air conditioning with electric fans in the general population (Morris et al, 2021). The authors found that electric fans are an appropriate way to manage risk of heat stress for adults in Australia when the ambient temperature is under 38°C. However, the authors also examined older people taking medication that may impair sweating function. They found impaired sweating function lowers the effectiveness of electric fans. This is because fans cool by both convection and evaporation (refer to 6.2 Fans for more detail). Therefore, the authors recommend supplementing electric fan use with air conditioning systems for people with impaired sweating function.

Most recommendations cited above are based on clinical opinion. Furthermore, the recommendations focus on achieving or maintaining cool indoor air temperatures, and rarely mention the means to achieve those temperatures. They do not differentiate between air conditioning and other space cooling strategies (evaporative cooling, ceiling fans, passive cooling).

6. Air conditioning and other cooling systems

Common home cooling systems include fans, evaporative cooling or refrigerated cooling. Sometimes the term air conditioning is used to refer to all these systems. Most often it is used to refer only to refrigerated cooling systems.

Not all systems will be appropriate in all circumstances. The most appropriate air conditioning system for a person will depend on factors including:

- environment – regional climate, average temperature, humidity
- building – size, layout, solar power, air flow and other passive cooling features
- occupancy – whole house or single room, rent or own, number of residents
- lifestyle – budget, habits, cooling needs, sustainability preferences (Wrigsley, 2023; Barnes, 2023; Lockyer, 2023; Milne et al, 2020; Gilmour & Steen, n.d.).

6.1 Cooling garments

Cooling garments can include jackets, vests, hats, hoods, gloves, wrist bands and thigh straps (Stevens et al. 2023; Laique & Hussain, 2018). Ren et al (2022) identify six types of cooling mechanism used in garments:

- ice cooling – garment contains insulated pockets to hold ice
- phase change materials cooling – made from a designed material that uses the latent heat from the body to lower the temperature of the microclimate between the body and the garment
- radiative cooling – made from a designed material that aims to maximise heat loss allowing more infrared radiation to escape the body
- thermo-electric cooling – garment contains conductors which can be used to directly draw heat energy from the body as an electric current is passed through the conductor
- liquid cooling – garment contains pipes carrying cold liquid and a pump to ensure liquid is spread over the garment

- air-cooling – garment that maximises ventilation through the use of design and small electric fans.

6.2 Fans

Fans work by moving air around a room more quickly. They do not cool the air, but rather aid the body's thermoregulatory processes. Faster moving air helps sweat evaporate more quickly (evaporation) and blows cooler air at the skin (convection). Fans are less effective in higher temperatures, though the exact threshold is still being debated in the literature (Morris et al, 2021; Milne et al, 2020; Iorio, 2019). Fans can be effective for healthy adults in temperatures up to 38°C (Morris et al, 2021) and may help to a lesser extent up to 42°C (Iorio, 2019). The Australian government's Your Home site states:

> Fans should be the first appliance of choice for cooling. They are cheap to run and generally use less energy than evaporative coolers or air-conditioners. Typically, the air flow created by a fan provides a similar improvement to comfort as reducing the temperature by around 3°C. With good design and insulation, fans can often supply adequate cooling for acclimatised residents in all Australian climates (Department of Climate Change, Energy, the Environment and Water; n.d).

Fans are most effective when aimed directly toward the body, in humid climates or when used in combination with water spray, wet clothing or wraps (Morris et al, 2021; Milne et al, 2020; Iorio, 2019; Department of Climate Change, Energy, the Environment and Water; n.d.).

6.3 Evaporative cooling

An evaporative cooler blows cool, humid air into a space by drawing outside air through a wet filter which is then expelled by a fan. An evaporative cooler may be less expensive to purchase and run than an air conditioning system, but this depends on the model. Evaporative coolers are less effective in humid environments and require large amount of water to operate (Milne et al, 2020; Department of Climate Change, Energy, the Environment and Water; n.d.).

6.4 Air conditioning (refrigerated cooling)

An air conditioning system that operates by refrigerated cooling draws warm air from inside the space and cools it via contact with a refrigerant gas. The cool air is blown back into the space and the extracted heat is expelled outside (Barnes, 2023; Milne et al, 2020; Barnes, 2019; Department of Climate Change, Energy, the Environment and Water; n.d.). Air conditioning systems can vary by cost, size, energy efficiency and type of refrigerant used. Air conditioners can be:

- fixed or portable
- single unit, split system, or multi-split system
- ducted or non-ducted

- reverse cycle or cooling only (Wrigsley, 2023; Barnes, 2023; Department of Climate Change, Energy, the Environment and Water, n.d.; Milne et al, 2020).

For comparison of purchase and running costs of different air conditioning systems in Australia, refer to 7. Air conditioning in Australia.

Reverse cycle air conditioning

A reverse cycle air conditioner operates in a similar way to a cooling-only system. However, a reverse cycle system is also able to reverse the refrigeration process, sending cold air outside and warm air inside. Reverse cycle air conditioners are often considered the most efficient systems because they can provide both heating and cooling. However, energy efficiency ultimately depends on a range of factors (Department of Climate Change, Energy, the Environment and Water, n.d.; Milne et al, 2020; Barnes, 2019).

Single unit, split system, or multi-split system air conditioning

Split system air conditioners have an outside unit and an inside unit. They are the most common fixed air conditioning systems and are usually more energy efficient than single unit systems. Split systems can be ducted or non-ducted. Multi-split systems have an outside unit and multiple indoor units, which can be placed in different rooms. They are an alternative to ducted systems (Barnes, 2023; Department of Climate Change, Energy, the Environment and Water, n.d.; Milne et al, 2020; Barnes, 2019).

Single unit systems are generally suited to smaller areas. They are generally less energy efficient than split systems. They can be fixed or portable. Portable systems are generally less expensive to purchase than fixed systems. They may be appropriate for smaller areas or when the system needs to be moved to different areas. They may also be appropriate when installing a fixed unit is not feasible, such as in rental properties (Lockyer, 2023; Milne et al, 2020; Barnes, 2019).

Ducted air conditioning

A ducted system is a central heating or cooling system, which means it is designed to warm or cool a whole house or building rather than a single room. Ducted systems can be evaporative coolers, reverse-cycle split systems or cooling only split systems. There is usually an outdoor unit on the roof and an indoor unit under the floor or in the ceiling. Ducts extend from the indoor unit and into multiple rooms or multiple areas of a bigger space (Department of Climate Change, Energy, the Environment and Water, n.d.; Milne et al, 2020; Barnes, 2019).

In terms of cost, ducted systems are generally more expensive to purchase, install and run, and therefore are generally less cost effective than non-ducted systems (refer to Table 2).

Installation is a significant upfront cost for ducted systems as work is required to install the roof unit as well as ducts throughout the home. Furthermore, ducted systems are not possible in some houses due to lack of space or other architectural features (King, 2023; Mullane, 2023).

Running costs are generally higher for ducted systems. Ducted systems may cool a large area faster than non-ducted single unit split systems, because the ductwork distributes the warm/cool air from a central unit. However, they are usually less energy efficient as they require a larger fan and some energy is lost as the warm/cool air travels through the ducts. As a central heating system, ducted air conditioning may waste energy if it is cooling or heating rooms that are not in use. Running costs may be partially addressed with well insulated ducting that limits energy loss. Running costs may also be reduced by using a zoned system that allows the user to switch on or off different sections of the home (Milne et al, 2020).

While ducted systems are generally less cost-effective than non-ducted systems, upfront and running costs vary widely depending on several factors (climate, temperature setting, maintenance schedule, system quality and features etc.). There may be circumstances in which ducted systems are ultimately more cost-effective. For example, if the user needs to cool a large house with multiple rooms or with very large rooms, a ducted system may end up less costly than installing multiple indoor units of a non-ducted split system. In one study based in Texas, a ducted system was compared to a non-ducted multiple split system. The authors found the ducted system was better at maintaining a constant temperature, better at humidity control and used almost 30% less energy (Bandari & Fumo, 2022). However, this study was conducted in a single house with only one model of each air conditioning system. It therefore cannot account for variables such as room size, insulation, climate etc.

Table 2 Cost comparison of ducted and non-ducted air conditioning systems

Costs	Ducted	Non-ducted
Purchase and installation cost	$9,000-$20,000 (King, 2023; Mullane, 2023)	• $600-$2800 (small) • $700-$3000 (med) • $1000-$5500 (large) (Richard & Iredale, 2023)
Running Costs (refer to Table 4)	• Cooling: $383-$1964 • Heating: $87-$1628	• Cooling: $30-$396 • Heating: $18-$528

7. Air conditioning use in Australia

Air conditioner use is increasing in Australia, up to a 2023 estimate of 86% of Australian households using air conditioning to cool their homes (Zander et al; 2023; Savvy, 2023; Godfrey, 2023; ABS, 2014). Half of households use fixed, wall mounted systems, which are evenly split between ducted and non-ducted systems (Energy Consumer Australia, 2023; refer to Table 3 for further details).

A non-ducted, reverse cycle, split system air conditioner can cost $500-$2000 plus installation costs of $600-$800. Annual running cost of a reverse cycle air conditioner at $30-$396 for cooling and $18-$528 for heating, depending on location and the size of the room being affected. Multiple units or ducted air conditioning may be required for bigger houses, in which case the purchase, installation and running costs could be significantly greater. Portable air conditioners can be cheaper to purchase ($500-$900) but are less energy efficient than split systems and will likely cost more to run (Lockyer, 2023; Wrigsley, 2023; refer to Table 4 for further details).

Table 3 – Percentage of households with heating or cooling systems (Source: Energy Consumers Australia, 2023)

Heating/cooling system	%
Wall mounted unit	50%
Ceiling fans	42%
Portable cooling	27%
Ducted air conditioning	26%
Portable heater	21%
Portable electric or gas heaters	16%
Gas central heating^	13%
Wood burning heater	9%
Ducted evaporative cooling	8%
Fixed fire	7%
Outdoor electric or gas heaters	4%
Electric panel heaters	3%
Electric underfloor heating	2%
Hydronic heating system	1%
None of these	3%

Table 4 – Comparison of average annual air conditioner (split system, reverse-cycle) running cost for ducted and non-ducted small, medium and large rooms in Australian capital cities (Source: Wrigsley, 2023)

City	Average Usage Rates (non-ducted)	Cool/Heat (Small)	Cool/Heat (Medium)	Cool/Heat (Large)	Cool/Heat (Ducted)
Brisbane	31.2c/kWh	$155/$46	$258/$20	$396/$30	$1964/$97
Darwin	28.1c/kWh	$140/$41	$232/$18	$357/$27	$1770/$87
Sydney	35.3c/kWh	$61/$193	$101/$153	$154/$232	$780/$726
Adelaide	44.9c/kWh	$78/$246	$128/$194	$195/$295	$992/$924
Perth	30.8c/kWh	$54/$169	$88/$133	$134/$203	$681/$634
Melbourne	26.3c/kWh	$30/$206	$48/$306	$73/$471	$383/$1451
Hobart	29.5c/kWh	$33/$231	$54/$343	$81/$528	$429/$1628
Canberra	26.4c/kWh	$30/$206	$48/$307	$73/$473	$384/$1457

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