Space cooling: More access, more comfort, less energy

Why discuss space cooling?

By understanding why increasing energy consumption for space cooling is a growing concern, we can properly develop effective policies and deliver efficient technologies. The five main reasons space cooling demand is on the rise include:

1. Wealth and comfort: An increasing desire for, and ability to afford, the thermal comfort provided by air conditioning
2. Population growth: Rising populations in countries with warmer climates and population shifts within countries from colder to warmer regions
3. Climate and temperature: Higher average temperatures and greater frequency of extreme temperatures due to local heat-island effects and climate change
4. Design and construction: Changes in building design and a shift from heavy materials such as stone or brick to materials with less thermal mass such as wood or composites
5. Electronic devices and appliances: An increasing quantity of personal electronic devices, appliances and office equipment in buildings that generate heat as a by-product

Each of these reasons, has varying levels of importance and impact on increasing energy demand for space cooling, with the growing desire for thermal comfort generally having the greatest impact.

Key point Demand for space cooling in buildings is growing fast, which will increase global energy consumption unless effective policies and efficient technologies are adopted.

What are the opportunities?

While many discussions start with the goal of reducing the energy used for cooling, long-term benefits can also be achieved by increasing cooling thermal comfort while reducing the need for space cooling. Both opportunities enable multiple benefits such as lower energy bills, fewer electricity capacity constraints and less use of climate-warming refrigerants.

Key point Broadly there are two key space cooling opportunities, (1) increasing cooling thermal comfort and (2) reducing the energy used to provide that cooling.

What should be done?

The choice of energy efficiency policies and technologies to address space cooling demand should be made using life-cycle calculations that account for the multiple benefits of energy efficiency. Policies and technologies should enable greater increased thermal comfort while reducing the total energy consumed.

Key point Key areas for energy efficiency policy are (1) cooling equipment (minimum energy performance standards) and (2) building envelopes. Key technologies are insulation, shading, windows and efficient air conditioners.

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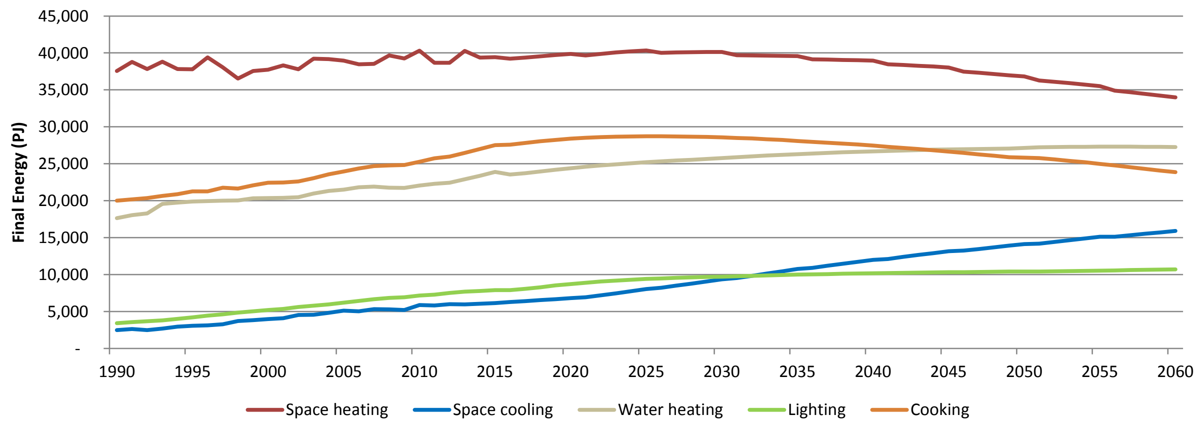
Energy demand for space cooling is rising

Space cooling is the fastest growing end use in buildings and could increase by as much as ten-fold in some emerging economies, such as Mexico, Indonesia and India. Unlike other sources of building energy demand, space cooling is not expected to plateau or decline by 2050:

Global building energy consumption by end use, 1990-2060



Source: IEA Energy Technology Perspectives 2017

Cooling comfort can be improved by reducing temperature, controlling humidity or increasing airflow. It can be delivered by equipment (e.g. air conditioners), mechanical ventilation (e.g. fans) or natural (passive) ventilation.

Space cooling technologies use a range of equipment types and components. Fundamentally, an air conditioner (A/C) moves heat from one space to another. An A/C can move heat from a range of thermal sources, including air, water or the ground. A/C equipment can be packaged as a single unit (e.g. package commercial chiller, portable A/C, window A/C or through-wall A/C) or split across multiple components (e.g. split and mini-split A/C, fan unit, chiller, cooling tower, or district cooling). Early A/C systems used fixed-speed fans and pump motors, but new energy-efficient systems typically use variable-speed components to adjust to a range of cooling loads. Cooling can be distributed through air or liquids.

The main reason energy demand for space cooling is increasing is the **desire for thermal comfort**. Fuelled by rising incomes, this is a positive sign of economic progress. However, greater comfort can be achieved more efficiently by producing more affordable, energy-efficient cooling technologies and improved building design.

Growing demand for space cooling in Mexico is a result of economic development and rising incomes. This has enabled a reduction in the number of persons per dwelling (thereby increasing the number of dwellings) from five in 1980 to approximately three persons per dwelling in 2010. It has also enabled rapid growth in sales of cooling equipment (split-system A/C) from 100 000 units in 2002 to more than 400 000 in 2013.

OECD (2015) Mexico Overview 2015, www.oecd.org/eco/surveys/Mexico-Overview-2015.pdf. Super-Efficient Equipment and Appliance Deployment Initiative (SEAD) (2015) Impacts Evaluation of Appliance Energy Efficiency Standards in Mexico since 2000.

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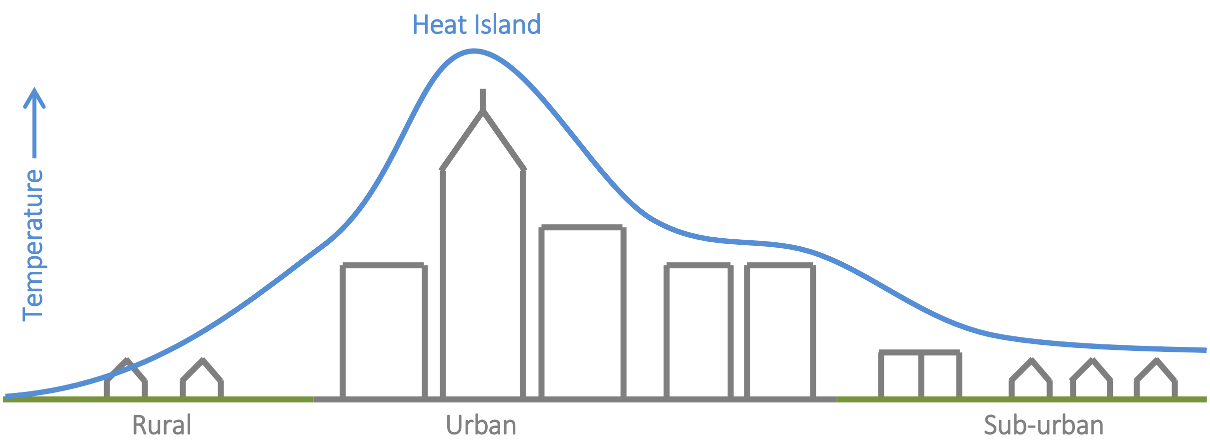
Many of the fastest growing countries and regions for cooling demand are in hot climates, due both to **population shifts** (from colder to warmer climates, enabled by greater thermal comfort from space cooling equipment) and higher **population growth** in emerging economies (mostly located closer to the equator). Global space cooling energy demand is also affected by **climate change**, through both gradual increases in average global temperatures and increases in peak temperatures during extreme weather events.

The affordability of air conditioners may have influenced population mobility. The United States was an early adopter of mechanical air conditioning, which grew from only 10% of buildings in 1965 to nearly 90% today. Population increases in hot climates since 1940 have been dramatic, with Miami, Phoenix and Las Vegas all having meteoric population growth (greater than 2 000%), while major northern cities of Chicago, Boston and Minneapolis shrank by more than 20%. Some northern cities have had populations plummet more than 55% since 1940. From 2000 to 2010, populations continued to shift from cold to hot climates; 88% of the States with low population growth were cold northern States and 80% of the States with high population growth were hot southern States.

Citylab (2012) website, www.citylab.com/work/2012/06/cities-might-not-exist-without-air-conditioning/2399/. Slate (2011) website, www.slate.com/articles/arts/culturebox/2011/07/a_history_of_air_conditioning.html.

In urban areas, there are a number of other negative influences, including less vegetation, more buildings and more roads that reject heat and reflect solar radiation. Population growth and urbanisation will exacerbate the impact of such "heat islands":



*Cooling demand has a direct link to outdoor temperature, and the release of hydrofluorocarbons (HFCs) from refrigerants used in cooling equipment is one cause of global warming. The recent Kigali Amendment adds HFCs to the substances controlled under the Montreal Protocol. The **Kigali Cooling Efficiency Program** (K-CEP) is an innovative programme working to improve energy efficiency in cooling concurrent with the phase-down of HFCs. K-CEP is working across four efforts in countries willing to move furthest and fastest: (1) Strengthening for Efficiency, (2) Policies, Standards and Programs, (3) Finance and (4) Access to Cooling.*

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Changing design and construction practice

Energy use for space cooling in buildings is also increasing because of changes in construction practices and design characteristics. Those changes include choice of materials, space-use design, and aesthetic design.

Choice of materials for floors, walls and the structure of the building have changed from heavy materials (e.g. stone, brick or concrete) to lighter and lower-cost materials such as wood, aluminium and composite materials that do not offer the same thermal mass. Thermal mass is important for space cooling (radiant temperature), as it holds heat (or cold) for longer, increasing thermal comfort.

Change in space-use design such as the building aspect ratio, the use of permanently closed windows, less use of spaces for seasonal "comfort zones" (e.g. covered porches or courtyards) and less use of passive cooling design (e.g. building orientation, shading or natural ventilation). This shift has resulted in greater thermal loads in buildings that require mechanical air conditioning.

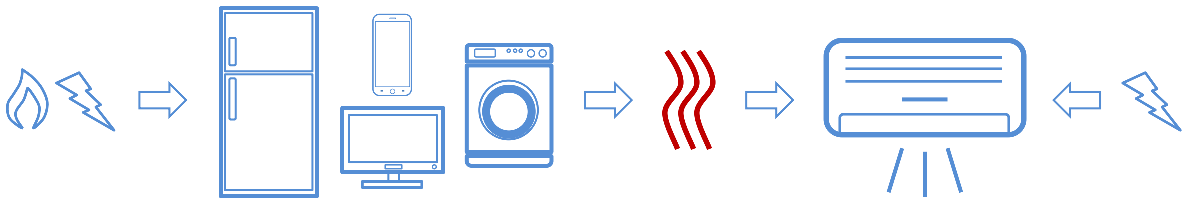
Change in aesthetic design includes architectural choice (e.g. all-glass façades) and the removal of visual clutter such as radiant panels, fans or in-room A/C units (e.g. mini-split type A/Cs) that deliver cooling via liquid. The latter can result in hidden ducted systems that deliver conditioned air from cooling equipment to the conditioned space that is (a) less efficient than liquid cooling distribution, (b) can have air leaks, and (c) often cools unoccupied spaces such as an attic, resulting in unnecessary energy consumption.

Increasing use of personal electronic devices and appliances

Growing use of personal electronic devices and appliances, including televisions, computers, office equipment and smart phones, releases heat into the ambient air and increases the need for space cooling in buildings. The use of any appliance impacts energy use in buildings in two ways, (1) the energy to operate the appliance and (2) the cooling energy used to remove heat gain from the appliance.

The energy consumed by an electronic device or appliance is emitted as heat or radiative heat both while in operation and in standby mode. This heat adds to an already large set of heat gains in buildings, including from bathing, cooking, lighting, and heat directly from people. All heat gains within a building add to space cooling loads and the energy needed to achieve thermal comfort.

Typically **more energy efficient appliances will use less energy and emit less heat**. While appliances have been getting much more efficient, they have also been greatly increasing in number. As the use of electronic devices and appliances continues to grow, the amount of energy needed in order to cool rooms to comfortable levels will also increase:



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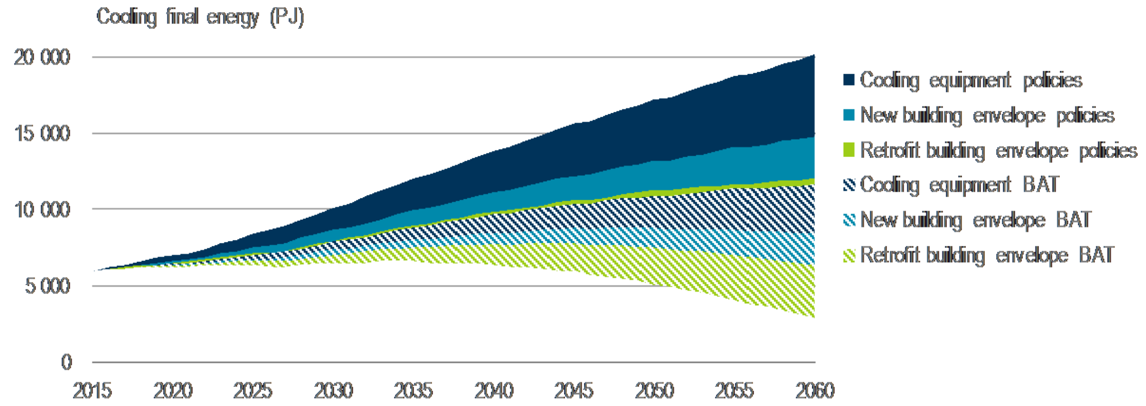
The IEA Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E) is a forum to share information, conduct projects and collaborate to support good policy design for energy efficiency in appliances and equipment. 4E membership is open to all countries and currently spans Asia-Pacific, Europe and North America.

Policies to improve energy efficiency in space cooling

A broad set of policies can be used to achieve energy efficiency in space cooling. Mandatory policies include building energy codes, certification and standards. Voluntary policies cover building energy management, energy labels, benchmarking, building improvement programmes (performance upgrades, weatherisation) and financial incentives (loans, grants, product pricing). These policies combined as a package can increase cooling thermal comfort while reducing energy consumption.

Globally, adopting best-practice policies could result in a plateau of space cooling energy use by 2060. If further effort is made to achieve adoption of best-available technologies, space cooling energy use could decline by 2040, and drop more than 50% by 2060 compared with 2015:

Global building cooling energy consumption and potential savings, 2015-2060



Source: adapted from IEA Energy Technology Perspectives 2017 and Energy Efficiency 2017

Policies that increase cooling thermal comfort

Policies that improve cooling thermal comfort while also reducing the need for cooling energy include: building energy codes, testing and labelling of technologies and materials, and obligation or finance programmes that focus on weatherisation and building energy retrofits.

Building energy codes set a minimum performance level for building envelopes, reducing the heat entering buildings and enabling improved thermal storage. Building energy codes that require effective ventilation remove heat and improve perceived comfort using air movement.

Testing and labelling for construction products helps ensure that they achieve the expected energy performance. Labelling building technologies and materials with performance characteristics can also improve purchasing decisions and code enforcement.

Building energy retrofit policies including energy efficiency obligations, disclosure, incentives or financing programmes enable action on existing buildings. Investment in energy efficiency in existing buildings is more effective when retrofit policies are co-ordinated with building codes, testing and labelling.

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Cooling thermal comfort policies often maximise the multiple benefits of energy efficiency for building owners and occupants. Policies should be designed to reduce life-cycle energy use, reduce embodied energy and increase the overall sustainability and energy savings of buildings.

Aiming for net-zero energy consumption in buildings is one of the *25 Energy Efficiency Policy Recommendations*. The World Green Building Council and lead partner Architecture 2030, have received commitments from national Green Building Councils to introduce a net-zero emission certification under the global project *Advancing Net Zero*. The United States Department of Energy defines a *Zero Energy Ready Home* as a high-performance home that is so energy efficient that a renewable energy system can offset all or most of its annual energy consumption.

United States Department of Energy website, energy.gov/eere/buildings/zero-energy-ready-home. World Green Building Council website, www.worldgbc.org/advancing-net-zero. Rocky Mountain Institute website, blog.rmi.org/blog_2016_08_15_To_Get_to_Net_Zero_Think_Bigger. Architecture 2030 website, architecture2030.org/advancing-net-zero-worldwide/

Policies that reduce the energy used for space cooling

Key policies to reduce the energy used for space cooling include (1) minimum energy performance standards (MEPS) and (2) energy labelling for air-conditioning equipment. Other policies include (3) linking renewable energy and space cooling and (4) building energy code life-cycle assessment.

MEPS for cooling equipment push the market towards equipment that will reduce energy use by eliminating the least efficient models and lowering the cost of more efficient equipment through a virtuous cycle of innovation and economies of scale.

Energy labelling of equipment enables consumers to make educated decisions as to the benefit of purchasing equipment with greater efficiency, and can also support building energy codes and energy efficiency programmes by making information more available.

Linking renewable energy and space cooling policies is an opportunity to promote two sets of technologies that are affected by solar energy. The solar energy that increases the need for space cooling can also enable renewable energy production, such as photovoltaic and solar thermal energy, that can be also used to operate fans and cooling equipment.

Building energy codes can ensure minimum energy performance of cooling equipment, controls and thermal distribution in buildings without reducing the energy performance of the building envelope. Performance path code compliance should not enable the reduction of long-term energy savings if short-life measures like appliances and equipment are traded off against long-life measures like insulation and windows.

Digitalisation (the use of smart technologies and data) in buildings is enabling more energy savings and personal comfort. These technologies include dynamic windows, automatic shades, and displacement ventilation. The Edge building in Amsterdam uses digital technologies (sensors, connected devices and a building management system) to improve energy efficiency. An aquifer thermal energy storage and heat-pump system provides heating and cooling, while smart ventilation and a heat exchanger remove excess heat from the atrium and reuse it. The data collected by this smart building is then shared with occupants to enable employees to locate working spaces that match their thermal comfort needs.

Bloomberg (2015) website, www.bloomberg.com/features/2015-the-edge-the-worlds-greenest-building/. BREEAM website, www.breeam.com/index.jsp?id=804.

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Technologies to reduce energy use in space cooling

Technologies that affect energy use for space cooling include both high-tech and low-tech solutions that can be designed during building construction or added by occupants later. When designed and operated correctly, those technologies can both increase comfort and reduce energy use.

Technologies that increase cooling thermal comfort

Technologies other than air conditioning can affect comfort by reducing heat gain entering a building, removing heat from interior spaces, temporarily storing heat or cold within a building and changing the perceived comfort of occupants.

Technologies that **reduce heat gain** entering a building include materials with high thermal resistance (insulation and windows), thermal mass (green roofs, heavy materials), solar protection (window film, dynamic windows, shutters, overhangs, trees) and solar reflectance (cool roofs, paint).

Technologies that **remove heat** from interior spaces include mechanical ventilation and natural ventilation. Ventilation (mechanical or natural) uses less energy than mechanical air conditioning, and if designed and operated properly, can remove the hottest air in a space to lower the average temperature.

Technologies that **store heat and cold** to reduce mechanical air conditioning include thermal mass (heavy envelope and furnishings) and phase-change materials. Materials that absorb heat when a space is hot can re-emit the heat when the space is cold.

Technologies that **affect perceived thermal comfort** include dehumidification and air movement (fans and natural ventilation). Dehumidification and air movement alone do not change the average air temperature within the space, but both provide improved comfort to occupants without the use of mechanical space cooling.

These technologies combine old wisdom and building design used prior to mechanical cooling with new technologies that can improve the thermal efficiency of buildings. The technologies range in cost effectiveness between existing buildings (e.g. fans) and new buildings (e.g. building envelope materials with high thermal resistance).

Passive architecture is a design philosophy that can improve thermal comfort. It consists of thermally isolating the building while also having controllable ventilation that enables indoor thermal comfort irrespective of external weather conditions. Many organisations have been working to promote and certify passive architecture, which can be found across a multitude of countries today, including Australia, Canada, Chile, China, Indonesia, Japan, Mexico, New Zealand, Korea, Turkey, the United Arab Emirates, the United States and most countries in Europe.

Passive House Australia website, www.passivehouseaustralia.org/what-is-passive-house. phius.org website, www.phius.org/what-is-passive-building-/the-principles. passivehouse.com website, passivehouse.com/02_informations/01_whatisapassivehouse/01_whatisapassivehouse.htm and passivehouse.com/03_certification/02_certification_buildings/02_certification_buildings.htm.

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Technologies that reduce the energy used for space cooling

Technologies to reduce the energy used for space cooling include high-efficiency cooling equipment, district cooling, cooling zoning within buildings, enhanced and predictive controls, advanced data analysis, and improved system maintenance. Those technologies – combined or in single applications – can drastically reduce energy use for space cooling in buildings.

High-efficiency air conditioners, heat pumps, chillers and evaporative coolers can provide the same cooling with less energy than inefficient cooling equipment. Improved components and software enable both improved peak energy efficiency and seasonal energy efficiency.

District cooling provides cooling through a network of insulated pipes, from a central point of generation to the end user. It enables multiple energy efficiency and renewable energy opportunities at system level. While district cooling alone is not necessarily more efficient than high-efficiency stand-alone air conditioners, the integration of renewable energy and thermal storage can make it highly efficient and cost-effective. District cooling's multiple benefits include increased usable area (floor and roof), less on-site noise and less maintenance.

Cooling zoning within buildings enables variation of temperature within a building, providing significant energy savings compared to a central cooling system that delivers consistent temperatures across the entire building. Cooling zoning can be achieved through room systems (mini-split air conditioners) or variable volume controls, dampers and valves.

Enhanced controls and predictive control can minimise the energy used to achieve thermal comfort within buildings. Enhanced controls (programmable and smart thermostats) enable cooling systems to turn off when additional cooling is not needed. Predictive controls use sensors and weather data to estimate how to most efficiently condition the building.

Improved technology maintenance can ensure that space cooling equipment and controls are working as they were designed and installed. Technology maintenance can ensure proper refrigerant charge, fan and filter cleaning, and control settings to improve overall system efficiency.

Many of these technologies can be easily deployed and are easily understood, are often the focus of short-term energy efficiency policies, and should be used in co-ordination with the technologies that increase thermal comfort, discussed above.

District cooling can enable renewable energy integration and thermal storage. Stockholm – a cold-climate city that built district cooling alongside an existing district heating system – has been able to increase cooling system efficiency through the use of both "free cooling" (natural cooling exchange with the sea) and recovery of excess cooling from heat pumps.

IEA DHC website, www.iea-dhc.org/the-research/case-studies.html. districtenergy.org website, www.districtenergy.org/case-studies/.

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