TREND
AIR CONDITIONING

In the Face of Global Warming, Air-Conditioning is Locked in a Market Model That is Costly for the Climate

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DATA OVERVIEW

Global warming through spatial cooling: global air conditioner demand unaffected by concerns of energy efficiency

The emissions from the space cooling sector totalled around 1 gigatonne of carbon dioxide equivalent ($GtCO_2e$) in 2019, tripling from the 1990 level[1]. Space cooling is, in fact, the "fastest-growing end-use in buildings".[1] As of 2016, the worldwide final energy use for space cooling in residential and commercial buildings combined was 2020 TWh, with cooling accounting for 18.5% of total electricity use in buildings, and around 8.5% of overall electricity use. This figure of final energy use represents electricity used for air-conditioning units, fans and dehumidifiers, as well as natural gas used for chillers, the latter representing only 1% of energy use in 2016.[1,2] Tracking these figures from 1990 to 2016 (**fig. 1**) shows a steadily increasing trend, with space cooling having taken up an increasing share in final electricity use, and as a share of overall building energy use.

As of 2018, 1.76 billion AC units were in use[3] – and around 2 billion units as of 2020– with the demand for units by 2030 expected to increase by another two-thirds, with the residential sector accounting for the largest share.1 Out of all ACs in use, around 70% are "Room ACs" or RACs– individual mini-split or self-contained AC units.[a] These are particularly popular in developing markets due to their lesser cost. RAC sales in 2020were estimated be 94.3 million units as per a study by Research And Markets, are expected to touch a record compound annual growth rate of 5.6% by 2026.[4] In a business-as-usual scenario, another study estimates the stock of RACs to reach 4.5 billion units by 2050, with China and India having the largest stocks, and accounting for more than half the expansion in number, followed by the US, Indonesia, Japan and Korea, the European Union, the Middle East, and Brazil.[5]

1.09 billion people around the world were identified as being at-risk due to a lack of access to cooling in 2021. In the same period, 2.34 billion people from the lower-middle income category will be able to afford an air conditioner or refrigerator, but one that is less energy efficient, because of higher costs.[6] At the present rate of increase, without major improvement made to the energy efficiency of cooling equipment, electricity demand for cooling in the building sector could increase by up to 50% by 2030.[1]

The African continent presents a unique picture, where the rates of AC use are presently low but set to increase exponentially in the coming years, driven by a warming climate and increasing incomes. The need for cooling will become a matter of survival, but also a key to ensuring the productivity of the workforce.[5] Currently, the largest market share in the air conditioning market is from South Africa (40%), followed by Egypt, while rapidly rising incomes in Nigeria are also expanding the market. In West Africa, the import of second-hand appliances from Europe is a major trend, which offers consumers cheaper options, at the cost of energy efficiency.[7]

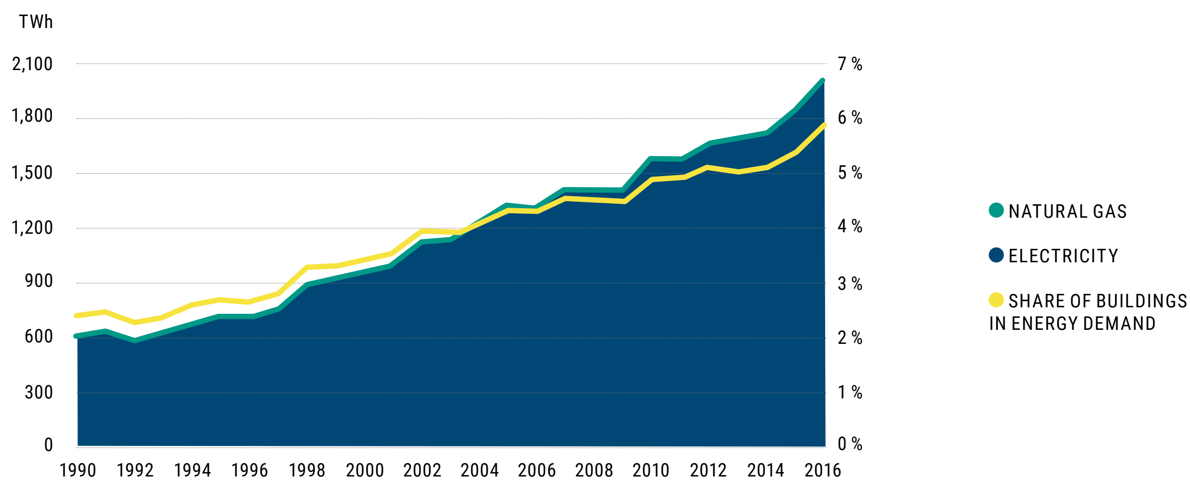
Looking at demand for cooling through unit sales, China, the US, and Japan dominated the cooling equipment (ACs, fans, chillers, etc.) market in 2019, with nearly 60% of the sales concentrated in these countries, while India and Indonesia have been seeing increasing yearly rates of AC installation, at 15% and 13% respectively.[1] There are several factors that affect the demand for cooling equipment, including the warming

a Mini-splits are air conditioners comprised of a single outdoor compressing/condensing unit and indoor air-handling unit, and have no need for air conditioning ducts. They are used to control the temperature in a single enclosed space – such as in an individual room – most commonly in the residential sector, but also in the commercial sector.

FIGURE 1

GLOBAL ENERGY CONSUMPTION FOR SPACE COOLING IN BUILDINGS, 1990 – 2016

Source : IEA, 2018.



global temperatures (measures in CDDs, or Cooling Degree Days[b]), increasing rates of urbanisation, a growing global population, and growing incomes.

An Enerdata study cited in Climate Chance's 2019 Sector-based report[8] found that income level, expressed as GDP per capita, had a higher correlation with air conditioner ownership than changes in climate, expressed in CDDs (**fig. 2**). Past trends in climatic conditions show that in most countries studied, even the warmer ones, AC ownership is not strongly affected by an increase in CDDs. Countries like the USA, Japan and South Korea seem to be nearing a saturation point in AC ownership, with little and slow increases observed between 2010 and 2018. Trends which could not be explained by climatic, or income factors were due to cultural influences, as in the case of China, as found in the study.[9]

Social and behavioural factors do Indeed play a large role in influencing energy demand for cooling in the residential sector. In the US, socio-economic factors like income proved to be intrinsic to household cooling energy consumption, with household income, size of the household and age of the occupants playing an important role, along with occupant behaviour, which in turn affected the frequency of air conditioner use and the number of air-conditioned rooms.[10] Socio-economic factors also often have an influence on the age and energy efficiency of air conditioners used. A study of seven cities from various climatic regions in China also highlighted the role of household income and size in influencing air conditioner use, along with characteristics of the dwelling itself such as the area, and the orientation of the building – in keeping with Chinese residential customs, most buildings are either North or South facing (rather than East or West), with South facing buildings recording higher temperatures.[11] In Saudi Arabia, where over 96% of properties studies were air-conditioned, thermal comfort (or its perception) and awareness about the existence of energy efficient or sustainable models also affect air conditioner use and demand.[12]

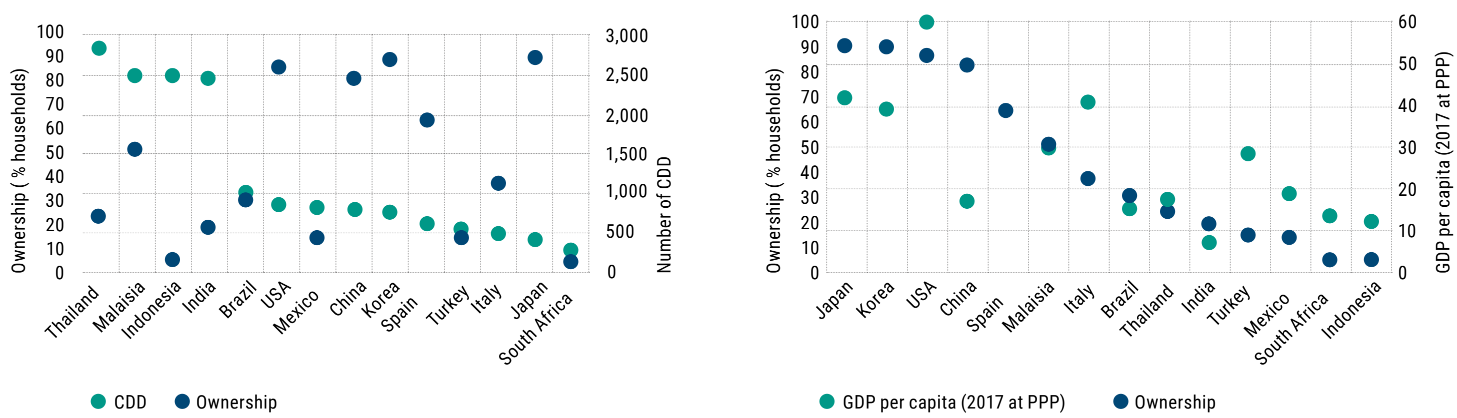
At the same time, the energy efficiency of space cooling equipment, most notably ACs, has been increasing. The Seasonal Energy Efficiency Ratio – SEER (**see Keys to Understanding**) – of residential and commercial ACs increased by 50% and 57% respectively, between 1990 and 2016[2]. While highly efficient units are available in the market presently, which could cut cooling energy demand in half if widely used, the typical units being sold are just 10-60% more efficient than the available minimum.[1]

b Cooling Degree Days, and Heating Degree Days or HDDs, are a measure of how hot or cold the outside temperature is (measured in degrees) and for how long (measured in days). It is the difference between the mean temperature of the day, and a reference temperature of 18°C. It is useful in calculating the heating or cooling energy requirements of buildings. An increase in CDDs would mean an increase in warmer days, and an increase in the need for cooling.

FIGURE 2

CLIMATE (COOLING DEGREE DAYS), GDP PER CAPITA AND AC OWNERSHIP PER COUNTRY

Source : Enerdata, 2019



KEYS TO UNDERSTANDING

ENERGY EFFICIENCY MEASUREMENTS OF ACs

ACs remove heat from a given space rather than transform it to another form. Thus, the energy efficiency of an AC is generally measured as a ratio of the amount of heat it removes from a space to the amount of power it consumes. Conventions vary geographically, with the metric changing based on the units used in each country – the metric system or imperial system – and also based on the purpose behind the measurement. One of the most commonly used metrics is the Energy Efficiency Ration or EER, which compares output cooling energy to input energy. For example, in the US, the EER is calculated as how many British Thermal Units (Btu) per hour are removed for every watt of power consumed, it is generally calculated using an outside temperature of 95°F (35°C), an inside temperature of 80°F (27°C) and relative humidity of 50% [2, 13]. The Seasonal Energy Efficiency Ratio or SEER measures the efficiency of the AC over an entire season, usually keeping the inside temperature constant but varying the outside temperature over a given period. These measures are often adapted to the country or region-specific climates (see **fig. 2** for examples of different regional metrics), and are often not inter-convertible. Different test conditions could also mean that ACs can have different EERs and SEERs.

FIGURE 3

EFFICIENCY RATINGS OF AC UNITS AVAILABLE IN SELECTED MARKETS, BY REGIONAL METRICS

Source : IEA, 2020

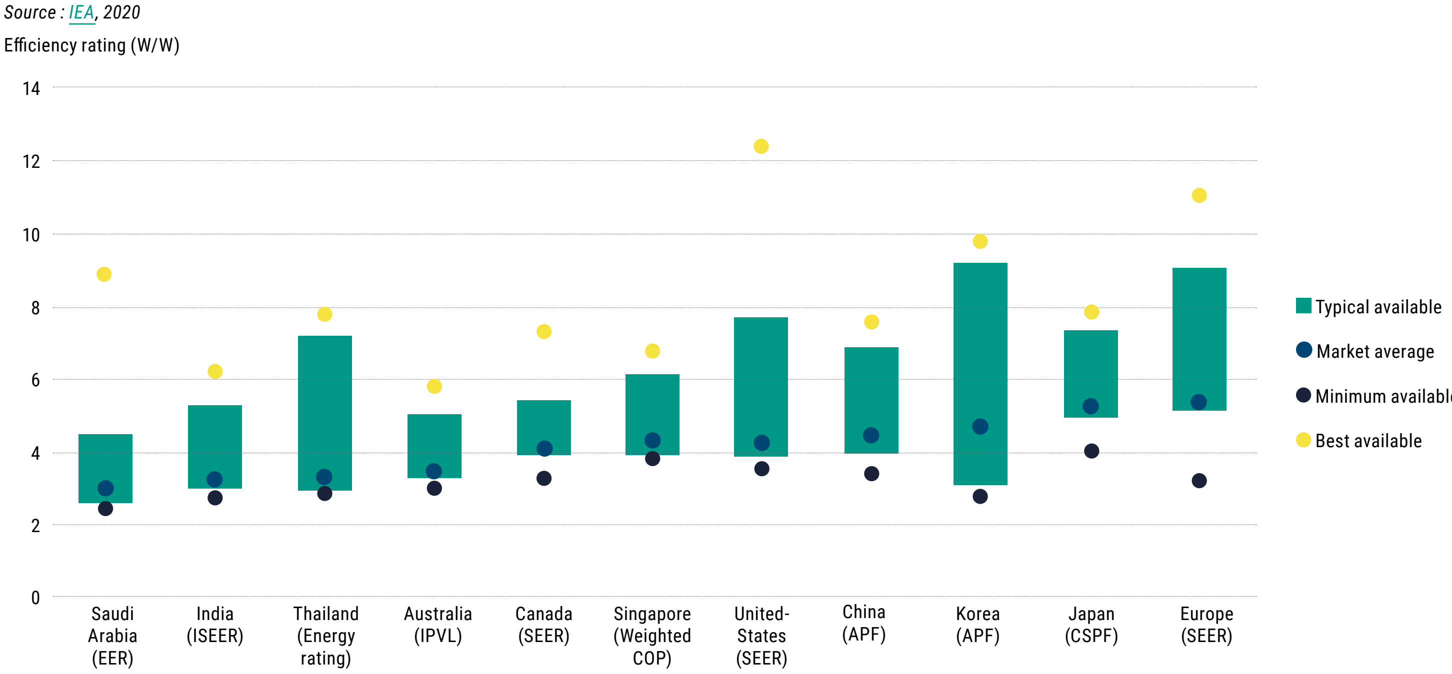


Figure 3 shows the range of efficiency of the most commonly available AC units in the selected countries, along with the market average and the available minimum and maximum ratings per market. In most cases, the market average is not much higher than the minimum, while more efficient alternatives do exist and remain available. The most significant barrier to the adoption of more efficient units was identified to be "consumer sensitivity to upfront costs", and a lack of awareness about the benefits of more efficient ACs[1].

Besides emissions arising from their energy usage, air conditioners can also impact climate change through refrigerant leakage – most commonly-used refrigerants are composed of hydrofluorocarbons (HFCs), whose Global Warming Potential[c] can be between hundreds to thousands of times as much as that of CO_2.[14] The Kigali Amendment to the Montreal Protocol, adopted by the United Nations in 2016, seeks to gradually phase down the use of HFCs in order to mitigate global warming cause by them, by cutting down on their production and consumption.[15] A three-step phase down has been agreed to, dividing the parties into three categories. Accordingly, developed countries have an earlier freeze date and are ti reduce HFC consumption by 85% by 2036 from their baseline. Developing countries are divided into two groups, both having a longer phase down schedule, later freeze dates, and later deadlines for 80-85% reductions from their baselines. The second group of developing countries consists of ones with high ambient temperatures, and higher demands for cooling, and this group has the longest schedule (Bahrain, India, the Islamic Republic of Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia and the United Arab Emirates).[16]

Thus, the demand for air conditioning is largely driven by cultural, social and climatic factors, less so by concerns about the energy efficiency of the equipment. Faced with the failure of individual choices to favour low-carbon air-conditioning solutions, some cities are trying to provide collective alternatives and curb the explosion in demand.

THE OBSERVATORY'S LENS

Cities cooling the fever pitch of air-conditioning

There are several actions being taken around the world, both to ensure access to cooling and to increase the sustainability of cooling solutions. On the part of national governments, most countries have already laid down Minimum Energy Performance Standards (MEPS) for air-conditioners, which act as qualifying conditions to sell AC units in the market. However, there remains a lack of harmonisation between various national standards. Several countries like Cuba, China, India, Panama, Rwanda and Trinidad and Tobago have published National Cooling Action Plans, while many other countries' Action Plans are in the pipeline, having been delayed by the Covid-19 pandemic.[17] These Action Plans work to identify vulnerable groups of population, ensure energy efficiency of cooling and to develop financial mechanisms to promote sustainable cooling.

Playing it cool, and circular: 5th generation networks for heating and cooling

At the local level, besides requirements in building or energy codes, a solution that is gaining ground is district cooling, and district energy systems that are adapted to both heating and cooling. District networks initially began as district level heating, powered by steam generated by coal, as early as the 1880's. These First Generation District Heating Networks (1GDH) have evolved over time, with the second generation shifting to the use of superheated water, and thus requiring less energy, to the third generation, popularised from the 1980's onwards, using water with lower supply temperatures to provide heating, and thus allowing for the inclusion of a wider variety of waste-heat sources such as industrial waste heat.[18,19]

The most recent developments have been the Fourth Generation District Heating (4GDH), and Fifth Generation Heating and Cooling (5GDHC) networks. 4GDH presents an evolution from the previous generations, incorporating more renewable energy and recycled heat, keeping the supply temperature levels as close as possible to the demand levels, and making wider use of thermal storage and heat pumps[19]. Fifth Generation networks are a simultaneous development, implemented almost parallelly to 4GDH, that use energy balancing and interaction between buildings to provide to both heating and cooling.[20]

5GDHC networks have so far mainly been piloted in smaller scales across Europe (**see Heerlen case study**). These demand-driven, decentralised networks are close to ground temperature, and use direct exchanges of warm and cold return flows, and thermal storage to maintain the desired

c The Global Warming Potential (GWP) of a gas is the amount of heat absorbed by it, presented as a multiple of the heat absorbed by an equivalent quantity of carbon dioxide. These figures are what help to calculate emissions in carbon dioxide equivalent (CO_2e).

temperature in buildings.[21] It prevents energy loss within the system by being a closed loop, and uses low-grade energy sources like shallow geothermal, industrial waste flows, conversion of waste, waste from cooling processes, sewage, etc.[22] A study of 40 selected 5GDHC networks in Europe, where they are in their initial phases, showed that they are most common in Germany and Switzerland, and more than two-thirds of these systems are regenerative (i.e. energy can be returned to the network); an analysis of the sources of energy in these systems showed that heat or cold from the ground and from various sources of water are the most common.[23]

While district heating has already been around and continues to grow in popularity, district cooling networks are increasingly gaining ground. The District Energy in Cities Initiative, for example, which is coordinated by the UN Environment Programme and SEforAll, works with 45 partners across private sector companies, international and national organisations, industry associations, city networks, and academic institutions to support market transformations to have renewable-powered and energy-efficient heating and cooling in cities. As of 2020, it had worked in 36 cities across the world, including Cartagena, Marrakesh, Belgrade, Pune, Coimbatore, Ulaanbaatar, Astrakhan and others, and had a projected reduction of 290,000 tCO_2/year in emissions.[24]

In the US, as part of Colorado's wider attempt to reduce GHG emissions from heating and cooling, the city of Denver is promoting the replacement of older natural gas-powered heating with electric heating and cooling, notably in the 30% of the residences, which fall in the low-income category, and do not have access to air conditioning. The city's plan offers seven full or partial electrification options, and Xcel Energy, an American electricity utility, offers rebates, even full rebates in certain conditions. According to a study by the City's Office of Climate Action, Sustainability and Resiliency, switching to renewable-powered electric heating/cooling works out to be around the same cost as natural gas.[25] Several American cities have taken measures in similar directions since 2019 (**see Electrification trend**).

District cooling networks have also been used by cities like Paris, which through the French utility Engie, runs a cooling grid which uses water from the river Seine, to cool hospitals, hotels, museums, and department stores. The Parisian network also offers an example of cool storage at the night, to be discharged at peak hours, which saves around 200 $kgCO_2$ a day.[26]

District cooling in the Middle East is one of the fastest expanding, with the market expected to cross a value $15 billion by 2027, dominated by Qatar, Saudi Arabia, and the UAE, led by eminent players like Tabreed, Empower, Emicool, DC PRO Engineering, Marafeq Qatar and Ramboll Group A/S.[27] Empower holds more than 70% market share in in the UAE, while the Engie, through its 40% stake in Tabreed is expanding its market across the region, and even to Egypt, India and Turkey.[28] In the GCC countries, district cooling and stand-alone air or water chillers represent 15-25% of installed cooling capacity, thanks to more recent real estate development, and the need to cut down on cooling energy demand. Additionally, 10% of the building stock in the region could eventually be retrofitted and connected to district cooling networks.[29] District cooling, while not new, is also gaining more ground in other parts of Asia as well, across China, Japan, and more recently, Southeast Asian countries. Singapore has also recently been investing in district cooling systems, such as in the financial districts, or more recently in the residential Tampines.[30]

Alternatives to air-conditioning in the conception and design of built environments

Making the best use of passive design principles and natural ventilation to replace automated HVAC systems is another key solution[31]. Using natural ventilation can reduce building energy consumption by 10 – 30%,[32] by using principles of air pressure to regulate the flow of cooler and warmer air currents in a building. For example, the design of the Japan National Stadium used for the 2020 Olympic Games at Tokyo, built largely with wood, and built to maximise airflow from the outside, helped bring temperatures down.[33] Several indoor venues for the games made use of 'green air tech' air-conditioning, which pushes air down in spirals to the lower parts of the building, and requires 40% less energy.[34]

Passive houses are buildings that are designed to capture and regulate naturally received heat and thus use up to 90% less energy than conventional houses.[35] They also have building envelopes that are designed for better insultation, and strategically placed windows and ducts. The Passive House Database lists 5,174 buildings that are certified as Passive Houses and are already completed or in the construction phase.[36] At the same time, the geographical distribution of certified buildings, as seen on the Passive House International database shows a concentration of these buildings largely in Europe, followed by North America, East Asia, Australia and New Zealand.[37]

The vast majority of identified Passive Houses are single-family homes and other small, low-rise buildings,[38] although larger applications have been made. The world's largest complex of passive houses is in construction in Gaobeidian, in China, which will consist of 30 high-rise buildings and house around 7,000 people.[39] The city of Brussels is another leading example in passive buildings, requiring all new constructions after 2015 to be passive, and also incentivising the construction 243 low-energy "exemplary" buildings, or BatEx.[40]

Reflective paint and "green" surfaces (surfaces with vegetation), particularly roofs, were identified in the 2020 Sector-based report[41] as popular requirements for new constructions. Planting vegetation in cities has shown to reduce temperatures by up to 45° F (~25° C),[42] while "ultra-white" reflective paint has been identified as reflecting excessive sun light and helping to cool buildings. This is not a new idea – white-painted buildings have been found traditionally in various regions with hotter climate. The calcium sulphate in white paint is responsible for reflecting solar radiation, and new studies identified barium sulphate as even more effective. The extraction of barium ore and producing barium sulphate, nevertheless, is energy consuming and has a rather large carbon footprint.[43]

The Million Cool Roofs Challenge was an initiative created to this end. By changing a dark roof to a white one, the temperature in the top floor can be reduced by 2-3 degrees. By increasing solar reflectance of the roof from 10-20% to 60%, net annual energy use for a single-story, air-conditioned building can be reduced by 20%.[44] The challenge, launched by the Kigali Cooling Efficiency Programme, SEforAll, the Global Cool Cities Alliance and the foundation Nesta, is providing $2 million in grants, between August 2019 and August 2021 to proposals for cool and solar-reflective roofing in countries affected by heat stress and low access to cooling. Finalists of the challenge who implemented the challenge in the Kerail slum in Bangladesh saw cool roofs reducing indoor temperatures by around 7°C. Similar results were yielded by adopting simple, reflective roofs in Jakarta, Indonesia.[6]

KEY TAKEAWAYS

The issue of cooling in buildings faces a double question of ensuring access to cooling in the face of rising temperatures and thus rising demand on the one hand, and on the other, the need to ensure energy efficiency and reduce GHG emissions. While innovation in cooling technology has been progressing, an equivalent advancement in equipment available for use in the residential and commercial sectors has not yet been made, nor has demand caught up. At the same time, the role social and behavioural factors in air conditioner use and purchase remains a large policy blind spot. District cooling, while not yet as widespread as district heating, is catching on, and remarkably so in the GCC, as the growing market invites energy giants from around the world to invest. Space cooling that capitalises on the design and conception of buildings is on the rise, as seen in the growth in passive houses, super-reflective surfaces, and green and cool roofs.

REFERENCES

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1 IEA. (2020). Cooling . *International Energy Agency*

2 IEA. (2018). The Future of Cooling : Opportunities for energy-efficient air-conditioning. *International Energy Agency*

3 IEA. (2019). Estimated air conditioner stock in selected regions, 2010-2018. *International Energy Agency*

4 Research And Markets. (2021). Air Conditioning Systems - Global Market Trajectory & Analytics.

5 Campbell, I., Kalanki, A., & Sachar, S. (2018). Solving the Global Cooling Challenge : How to Counter the Climate Threat from Room Air Conditioners. *Rocky Mountain Institute.*

6 SEforAll. (2021). Chilling Prospects : Tracking Sustainable Cooling for All 2021.

7 Goldstein Market Intelligence. (2020). Africa Air Conditioner Industry Analysis : By Product Type (Split, Rooftop, Chillers, VRF), By End-User (Residential & Commercial), By Region (Nigeria, Egypt, South Africa, & Others) With COVID-19 Impact.

8 Observatory of Non-State Climate Action. (2019). Global Synthesis Report on Climate Action by Sector. *Climate Chance*

9 Enerdata. (2019). The Future of Air-Conditioning

10 Yun, G. Y. & Steemers, K. (2011). Behavioural, physical and socio-economic factors in household cooling energy consumption. *Applied Energy, 88(6)*. pp. 2191-2200.

11 Wu, J. et al. (2017). Residential air-conditioner usage in China and efficiency standardization. *Energy, 119*. pp. 1036-1046.

12 Aldossary, N.A., Rezgui, Y. & Kwan, A. (2015). An investigation into factors influencing domestic energy consumption in an energy subsidized developing economy. *Habitat International, 47*. pp 41-51.

13 CTCN. (n.d.). Efficient air conditioning systems.

14 UNFCCC. (n.d.). Global Warming Potentials (IPCC Second Assessment Report).

15 UNEP. (n.d.) The Kigali Amendment to the Montreal Protocol : HFC Phase-down.

16 European FluoroCarbons Technical Committee. (n.d.) Regulations affecting HFCs.

17 SEforAll. (05/05/2021). National Cooling Action Plans.

18 Thorsen, J.E., Lund, H., & Mathiesen, B.V. (2018). Progression of District Heating – 1st to 4th generation. *Aalborg Universitet.*

19 Lund, H. et al. (2021). Perspectives on fourth and fifth generation district heating. *Energy, 227.*

20 Buffa, S. et al. (2020). Fifth-Generation District Heating and Cooling Substations : Demand Response with Artificial Neural Network-Based Model Predictive Control. *Energies.*

21 Boesten, S., et al. (09/2019). 5th generation district heating and cooling systems as a solution for renewable urban thermal energy supply. *Advances in Geosciences, 49*, 2019. pp.129-136.

22 D2Grids. (04/02/2021). The 5 principles of 5th generation district heating and cooling. *Construction 21.*

23 Buffa, S. et al. (04/2019). 5th generation district heating and cooling systems : A review of existing cases in Europe. *Renewable and Sustainable Energy Reviews, 104*. pp.504-522.

24 UNEP. (04/02/2021). District Energy in Cities Initiative.

25 Prentzel, O. (16/06/2021). About 30 % of Denver's homes lack air conditioning. Here's the city's environmentally friendly solution. *Colorado Sun.*

26 Di Cecca, A., Benassis, F., & Poeuf, P. (n.d.) Energy Storage : The Parisian District Cooling System. *UNEP-European Energy Centre.*

27 Global Market Insights. (11/04/2021). District Cooling Market in Middle East to hit $15 Bn by 2027.

28 Mechanical Electrical & Plumbing. (2019). Market Focus : district cooling in the Middle East.

29 Strategy&. (2019). Cooling our world : How to increase district cooling adoption through proven regulation.

30 Ng, M. (20/08/2021). Cool new way to help transform Tampines into eco-town by 2025. *The Straits Times.*

31 ArchDaily. (23/06/2021). Back to Basics : Natural Ventilation and its Use in Different Contexts.

32 Walker, A. (2016). Natural Ventilation. *Whole Building Design Guide.*

33 Sidhu, J. (16/08/2021). What cities can learn from the cooling systems at the Tokyo Olympics. *World Economic Forum.*

34 Oliver, H. (23/08/2021). Tokyo is showing other cities how to cool the eff down. *TimeOut.*

35 McCord, M. (26/01/2021). What exactly is a passive house – and could it be the future of sustainable housing?. *World Economic Forum.*

36 Passive House Database. (n.d.)

37 PHI Database.

38 Wilson, J. (2018). When Passive House goes big. *BuildingGreen.*

39 International Passive House Association. (2019). 23rd International Passive House Conference in Gaobeidian, China.

40 Building Innovations Database. (n.d.) Brussels Exemplary Buildings Program + Passive House Law of 2011.

41 Observatory of Non-State Climate Action. (2020). Global Synthesis Report on Climate Action by Sector. *Climate Chance*

42 Hotz, R.L. (04/06/2021). To offset climate change, scientists tout city trees and ultra-white paint. *The Wall Street Journal.*

43 Parnell, A. (07/06/2021). Cooling buildings by nearly 5°C possible thanks to new whiter-than-white paint. *The Conversation.*

44 Cool Roofs Challenge. (2020). Purpose of the Challenge.