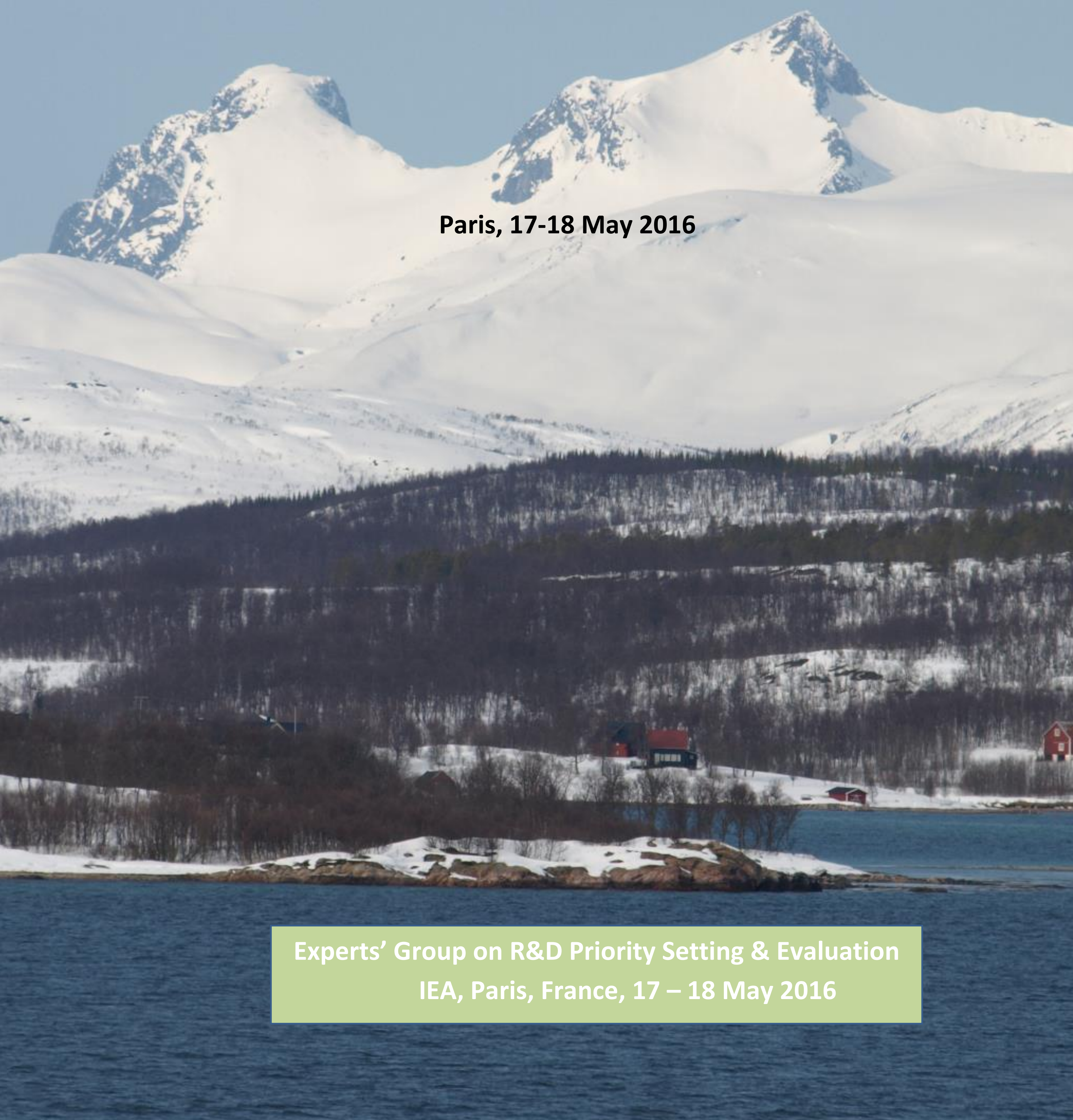
Workshop on Space Cooling

summary report



Paris, 17-18 May 2016

Experts' Group on R&D Priority Setting & Evaluation

IEA, Paris, France, 17 – 18 May 2016

International Energy Agency

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its mandate is two-fold: to promote energy security among its member countries through collective response to physical disruptions in oil supply and to advise member countries on sound energy policies. The IEA carries out a comprehensive program of energy cooperation among 29 advanced economies,[1] each of which is obliged to hold oil stocks equivalent to 90 days of its net imports.

The Agency aims to:

- Secure member countries' access to reliable and ample supplies of all forms of energy—in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context, particularly in terms of reducing greenhouse gas emissions that contribute to climate change mitigation.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organizations, and other stakeholders.

IEA Experts' Group on R&D Priority Setting and Evaluation (EGRD)

The capacity of countries to apply sound tools in developing effective national research and development (R&D) strategies and programs is becoming increasingly important. The EGRD was established by the IEA Committee on Energy Research and Technology (CERT) to promote development and refinement of analytical approaches to energy technology analysis, R&D priority setting, and assessment of benefits from R&D activities.

Senior industry and policy experts engaged in national and international R&D efforts collaborate on topical issues through international workshops, information exchange, networking, and outreach. Nineteen countries and the European Commission participate in the current program of work. The results and recommendations provide a global perspective on national R&D efforts that aim to support the CERT and feed into analysis of the IEA Secretariat. For further information, see: https://www.iea.org/about/standinggroupsandcommittees/cert/.

For information specific to this workshop, including agenda, scope, and presentations, see: https://www.iea.org/workshops/egrd-space-cooling.html

This document reflects key points that emerged from the discussions held at the workshop. The views expressed in this report do not represent those of the IEA or IEA policy nor do they represent consensus among the discussants.

[1] Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States; the European Commission also participates in the work of the IEA.

The Workshop on Space Cooling

The *Space Cooling* workshop was held on 17-18 May, 2016, in the IEA head office in Paris, and was organized by the EGRD. The workshop is part of a series organized within the EGRD's three-year mandate (2014–2016) as granted by the CERT.

This workshop summary report provides an executive summary, the meeting rationale, and summaries of the experts' presentations and discussions.

In addition to the EGRD national experts, input was provided by RD&D decision-makers, strategic planners, and program managers from industry concerned with space cooling technologies and technologies to decrease or avoid the demand for space cooling. Participation was by invitation only.

On behalf of the EGRD,

Rob P. Kool, RVO.nl

Birte Holst Jørgensen, Technical University of Denmark

Herbert Greisberger, NEU

Atsushi Kurosawa, IAE

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Executive Summary

The IEA's Experts Group on Energy R&D and Priority Setting organised a workshop on 17-18 May 2016 in Paris, France. The workshop focussed on space cooling and addressed the reason for the increase in energy demand for space cooling as well as available and future technologies and policies to meet the demand in various countries. With input from speakers representing public authorities, research and the private sector, the participants discussed key technologies, innovation, target-oriented RD&D programs and reasonable incentives to reduce the energy demand responsible for CO_2-emissions from space cooling.

Experts agree that energy demand for cooling is growing fast. Sales of simple air-conditioning units on are growing exponentially, partly because they have become affordable for many citizens in countries like India, China and parts of Latin America. This process is stimulated by increasing welfare as cooling is considered a luxury good and people can afford more comfort!

, . Further, demand is growing because of climate change. The latter is not just caused by general rise in temperature, but by the development of so-called hotspots. Especially in dense urban areas these "heat islands" are responsible for an increased local energy demand.

Although it is generally acknowledged that the energy use for space cooling is increasing, existing statistics on global and regional demand are proprietary and limited which might not be well suited for public dissemination and public decision makers.

A portfolio of technologies and mechanisms aim at reducing overall energy use for space cooling, but cooling is also used to reduce peak load (especially in warehouses and supermarkets). The RD&D aim at developing alternative lower global warming potential (GWP) refrigerants, the improvement of technology like vapour compression, adsorption heat pumps, thermos-elastic or membrane cooling systems and the combination of mechanical cooling and renewable (solar) energy. The last combination is interesting because the cooling and energy production peaks are similar.

The efficiency of cooling is strongly climate dependent. Cooling in humid climates is far less effective than in dry areas, something which technologies manage. RD&D focus on how to reduce or avoid the use of energy for cooling, including better insulation and passive cooling. Design is also a prioritised RD&D area, ranging from optimised passive use and insulation to the development of efficient and effective district cooling. Experts discussed the tipping point to go from individual (or even personal) cooling to central and distributed systems and found that this trade off was very context specific and needed more research.

On the policy side there are a couple of topics. Relatively high global warming potential (GWP) refrigerants like the hydrofluorocarbons (HFC) R134a and R410A are used in increasing measure in the developed world as substitutes for phased-out ozone depleting refrigerants for space cooling and other applications. Concerns about global climate change are driving increasing pressure to reduce, and finally ban their use in favour of lower GWP alternatives. Labelling on the other hand is driving technology to be more energy-efficient especially if supporting a development towards (near) zero buildings. Efforts also include integrated energy policy approach combining buildings, cooling and behavioural mechanisms. With the launch of the Mission Innovation in December 2015 and the pledge by member states to double their energy R&D funding by 2020, it is expected that technological and systemic advances in cooling space will be prioritised.

Rationale

The demand for space cooling in the built environment is growing rapidly worldwide, especially in emerging markets of equatorial hot and hot, humid climates. Even in many cooler climates, space cooling energy use in buildings is increasing, as demand for improved (and adjustable) thermal comfort grows. For instance, district cooling in Sweden increased from roughly 350 gigawatt-hours (GWh) of delivered thermal energy in 2000 to nearly 1,000 GWh in 2013 (IEA CHP/DHC Country Scorecard: Sweden, 2016).

Space cooling currently accounts for an estimated 5% of total final energy consumption in the buildings sector (ETP 2016, 2016), but it is the fastest growing end use in buildings (ETP modelling estimates). Cooling demand is dependent on numerous factors, some of which are more easily quantifiable than others, including climate, internal heat loads (from occupancy and equipment), occupant behaviour (including occupant comfort levels), level of system controllability, architectural and material choice, and the size and design of a building (where natural cooling many not be possible because of building depth or inoperability of windows).

Global urbanisation will also have an impact on cooling demand. Urban environments with large, multi-story buildings typically have higher space cooling demand. Urban heat island effects can also significantly raise temperatures – and cooling demand – in cities.

The IEA Secretariat has analysed space cooling demand as part of its energy demand scenarios to 2050 under both the *World Energy Outlook* and *Energy Technology Perspectives* publications. Current IEA estimates show space cooling demand growing as much as tenfold in some regions, while global cooling demand increases by 2.5 fold by 2050. Other (external) energy forecasts predict even higher space cooling demand growth. The IEA, therefore, seeks to improve its assessment of space cooling demand as part of its continued work stream on thermal energy loads in buildings. Work under the Energy Efficiency in Emerging Economies (E4) programme – with strong links to energy demand technology and policy in Mexico, Indonesia, India and South Africa – is also supporting this effort**.**

At the same time, research and development is pursuing technology options to reduce the energy demand associated with space cooling, or mitigate the growth in such demand. Many existing technologies have been optimized for temperate climates, but not so for high temperature and/or humid climates, where much of the rising demand is sourced. Further, there is international desire to eliminate or reduce the use of high global warming potential (GWP) HFCs as working fluids in space cooling equipment. HFCs are now prevalent as substitutes for CFCs, which are ozone depleting substances. This has led to a resurgence of innovation in technical options in this area.

In order to better estimate space cooling demand, and assess the barriers to various modalities of solutions, several critical issues need to be assessed.

- First, within the IEA modelling outlooks, **population weighted cooling degree-days (CDDs)** are needed to estimate how much cooling would be demanded across different regions relative to different comfort levels. E4 work in Mexico, using population forecasts by city in Mexico to 2050, recently looked at cooling demand relative to different thermal comfort levels (e.g. a Mediterranean level of comfort relative to US level of comfort) per population weighted CDD. Whereas previous ETP analysis had estimated a threefold growth in building cooling demand in Mexico to 2050, this new assessment found that even under a more conservative approach, cooling demand in Mexico could increase by fivefold or more. Improved assessment – using regional CDD values – is therefore a critical area of action in improving modelling scenarios to 2050. Further, the question of occupant behaviour (preferred temperature; tendency to open windows) is one of the most significant sources of uncertainty in building energy use and is the subject of work on improving modelling of behaviour.
- **Building envelope efficiency** is another critical factor in assessing building cooling demand more accurately. The IEA Secretariat has worked with partners to improve assessment of thermal loads (in terms of final (input) and useful (output) energy demand) and building envelope technology potential. Large potential energy savings can be achieved through building design (either passive – e.g. building shading – or active – e.g. electrochromic glazing for windows), but additional work is needed to better assess to what point building envelope measures are cost effective relative to other energy saving measures (e.g. high efficiency cooling equipment or district energy supply).
- A third area of cooling assessment is technical potential (in terms of cooling equipment) relative to various environmental conditions. Presently, large portions of building cooling demand are in regions with relatively low latent (e.g. humidity) loads. Beyond core technical developments (e.g. improvements in heat pump technology performance), **treatment of both latent and sensible cooling loads** in many hot, humid regions will be an issue – especially as passive building design alone may not be able to address comfort with high latent loads.
- **Expected technical performance** (e.g. heat pump co-efficient of performance [COP]) should also be addressed. If fundamentally the world is shifting to a mechanical cooling environment, then much more effort will be needed to ensure very high cooling equipment efficiencies. Achieving expected technical performance also requires training, including both design (proper equipment sizing calculations have safety factors built in, plus engineers add their own safety factors which leads to the installation of a very conservative or oversized HVAC equipment), commissioning, and operation.
- Last, other **technically related issues, such as refrigerant choice** in cooling equipment, are of interest, as these issues may have energy and environmental impacts. There is currently work underway to use CO_2 as a refrigerant in heat pumping equipment, and district cooling – especially using natural cooling and variable renewables input – has made noticeable progress in some regions. In addition to CO_2, there is work on developing other low-GWP replacement refrigerants, particularly HFOs. Natural refrigerants, e.g., propane, are also being examined. Another avenue for inquiry would be variable refrigerant flow (VRF) systems. Additional research in these areas – especially with respect to technical efficiency potential and environmental impact – would be valuable.

Current Activities

There are many activities addressing this topic ongoing throughout the world, including in the United States, Japan, Mexico and Europe. Some excellent work across these various areas is already taking place in the IEA Energy Technology Network through its Technology Collaboration Programmes (TCPs) including, in particular, Heat Pumping Technologies (HPT TCP), Buildings and Communities (EBC TCP), and District Heating and Cooling (DHC TCP).

Questions

Questions to be addressed by the participating experts include:

- *What do scenarios forecast for future energy demand for space cooling?*
- *What are the main drivers for increasing demand for space cooling?*
- *Which measures can be taken to stabilize the energy demand for space cooling?*
- *How is space cooling handled in different countries?*
- *How does occupant behaviour relate to energy demand for space cooling?*
- *To what extent does the age of the population influence the demand?*
- *Do regulation and/or higher comfort standards influence the demand for space cooling?*
- *Does the greenhouse effect influence the demand for space cooling?*
- *Does the increase in energy efficient devices reduce the demand for space heating in offices and private households?*
- *Is there a correlation between indoor climate and labour productivity?*
- *Can the problem of growing energy demand for space cooling be solved through energy efficient construction?*
- *How can demand side management help to minimize the need for space cooling?*
- *Which technologies for space cooling are currently used?*
- *What is the current status of technology for space cooling?*
- *To what extent can the energy demand be reduced by energy efficient devices?*
- *To what extent can new refrigerants contribute to reducing the problem?*
- *Can or to what extent can solar energy solve the problem?*
- *What progress can be expected in the foreseeable future?*
- *To what extent can geothermal cooling contribute to solving the problem?*
- *How can thermal energy storage systems (phase change material, ice storage) assist in shifting the cooling load for building owners and lowering the peak demand for utilities?*
- *After all energy load reducing measures are implemented, what technologies are there to assist buildings in approaching zero energy?*
- *How is thermal energy storage accommodated in heavily urban environments?*
- *Does the regulatory framework need adjustment to lower energy demand for space cooling?*
- *How can standards and labels for buildings and cooling devices be implemented effectively?*
- *How can R&D contribute to minimization of CO_2-emissions related to space cooling?*
- *Can replacement refrigerants contribute to reducing refrigerant Global Warming Potential?*

Report Structure

This report summarizes the workshop findings, providing summaries of each presentation. Following this section, the report follows the agenda from the workshop, with five session chapters:

- Session 0 – Introduction
- Session 1 – Future Demand for Space Cooling
- Session 2 – Technological Options to Reduce Energy Demand for Space Cooling
- Session 3 – Barriers to and Supporting Factors for Low Energy Demand for Space Cooling
- Session 4 - Public Policies Toward Space Cooling
- Session 5 – Wrap-up & round table

A list of additional source material/session is added.

Appendices to the report provide a list of acronyms, workshop participants, and the workshop agenda.

Presentations are available at http://www.iea.org/workshops/egrd-space-cooling.html

Summary of Sessions and Presentations

Summary Session 0: Introduction

This session had two presentations, a general introduction to the EGRD and the rational of the workshop and an overview of the topic by the IEA

Introduction to the workshop and the EGRD

Rob Kool, Chair of the EGRD; Energy Expert, Netherlands Enterprise Agency RVO.NL, Government of the Netherlands

- Link to presentation slides: http://www.iea.org/media/workshops/2016/egrdspacecooling/1.RobKool.pdf

The Experts' Group on R&D Priority Setting and Evaluation (EGRD) is part of the IEA's Technology Network. The EGRD examines analytical approaches to energy technologies, policies, and research and development (R&D). The group's recommendations support the Committee on Energy Research and Technology (CERT) and can:

- Support the methodology of priority setting and evaluation, contributing to theory
- Evaluate results: discuss IEA theoretical output with the "practitioners in the field" like roadmaps (always in collaboration with the IEA Secretariat)
- Support cross-cutting efforts by combining IEA fields of expertise to accelerate processes or identify blind spots

The Cooling Space Workshop is part of a three-year programme that covers six different topics. This workshop addresses the increasing energy use for cooling.

The demand for space cooling in the built environment is growing rapidly worldwide, especially hot climates. But even in many cooler climates energy use for space cooling in buildings is increasing, as demand for improved (and adjustable) thermal comfort grows.

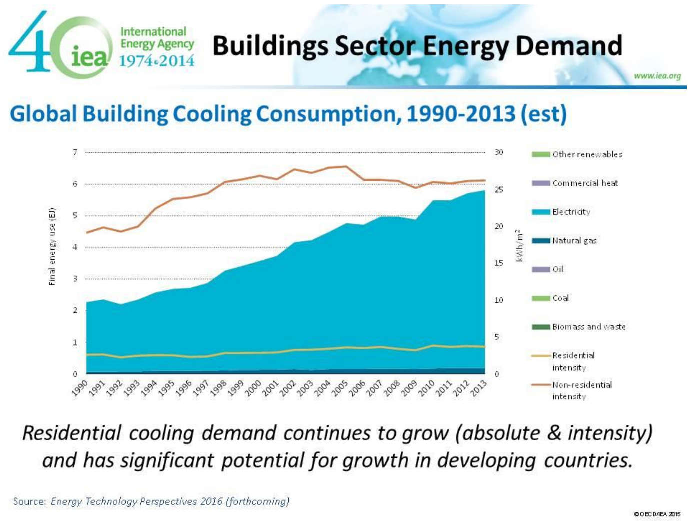
At this moment space cooling accounts for approximately 5% of the energy consumption in the buildings sector and is the fastest growing end use in buildings (ETP modelling estimates). Global urbanisation and urban environments with multi-story buildings have even higher space cooling demand. This could lead to urban heat island effects with significantly rising temperatures – and cooling demand – in cities.
To contribute to the global goals to reduce the use of energy the workshop looks at four major themes: Future Demand for Space Cooling, Technological Options to Reduce Energy Demand for Space Cooling, Barriers to and Supporting Factors for Low Energy Demand for Space Cooling and Public Policies Toward Space Cooling. Results, report and presentations are available on the EGRD page of the IEA website.

Global energy demand for space cooling in 2050

John Dulac, Energy Analyst, IEA Energy Technology & Policy Division

- Link to presentation slides: http://www.iea.org/media/workshops/2016/egrdspacecooling/2.JohnDulac.pdf

Data from Energy Technology Perspectives[2] for Buildings Outlooks and strategic plans for cooling in buildings were presented. Residential cooling demand continues to grow (absolute & intensity) and has significant potential for growth in developing countries. Exact data are not available, but based on the available information it is fast growing on the moment. Cooling growth could be cut significantly through improved building envelopes and more efficient cooling technology. Especially in the NON-OECD countries, the expected growth in business as usual would make it hard, if not impossible to achieve the 2°C scenario[3].



The country analysis of Mexico illustrated that we need improved assessment – and inputs – on demand for comfort across climate and building types. The long term estimates make it clear that the trend is to use more energy for cooling, but by how much is very uncertain.

Understanding demand and getting It right is the challenge. So what is next?

On the demand side we will have to get improved resolution on CDD relative to population growth, especially in developing countries and a better understanding (across scenarios) of cultural norms / expectations / shifts in thermal comfort. Also there is necessary to distinguish between latent & sensible heat, especially in developing countries.

On the technology side, we need better knowledge of the technical potentials for cooling equipment and efficiency / cost curves on building shell relative to climate zone. This also includes the separation of latent and sensible heat and its implications for equipment.

[2] www.iea.org/ETP
[3] https://www.iea.org/publications/scenariosandprojections/

Summary session 1: Trends

Birte Holst Jørgensen, the Technical University of Denmark (DTU)

This session analysed the current and projected demand for space cooling globally, as well as for selected regions of interest.

We are faced with an increasing demand for cooling, especially in emerging economies like India, Southeast Asia, Brazil and China

- Factor 30 increase in AC by 2100 or moderate/deep forecast
- In Germany we saw the highest demand especially in non-residential buildings, though food cooling is actually much larger (67%)
- There were many models, some more useful than others, but yet more will be necessary to support decisions
- The topic was including phase out of HFC, along with mitigation of CO_2 (to support policies regarding the Montreal protocol)
- To quality cooling with solid data is a huge problem even in a country like Germany

The major drivers behind the increasing demand are: Climate change (with increasing temperatures, population growth and GDP growth. On top of that we see a demand for more comfort, more space and more appliances in households (AC penetration – not necessarily as high as US with 95%).

Technology wise we saw simple and more sophisticated technology solutions – a question about doing cold smarter:

- Exploit ”wasted” cold (not that we have to go back to import ice from Norway as during the Industrial revolution)

- A technology roadmap on cooling should be developed covering:

  - Making, storing, moving, using and managing cold.
  - Cooling concepts: ventilation, cooling (type of heat transfer air or water) and heat sink
- There are already simple, effective solutions:
  - doors as standard in supermarket freezers, as are already in use by some big retail chains (Tommie Mansson challenged this in a later presentation)
  - use sprinkler tanks for usage as cold storage for load shifting of cooling load from day to night (Harald Blazek)
- Concerning concepts and climate zones we saw:
  - passive and ventilation in cold climate and radiant cooling in warmer climate
  - energy transformation needs more energy flexible buildings with heat pumps, and chillers

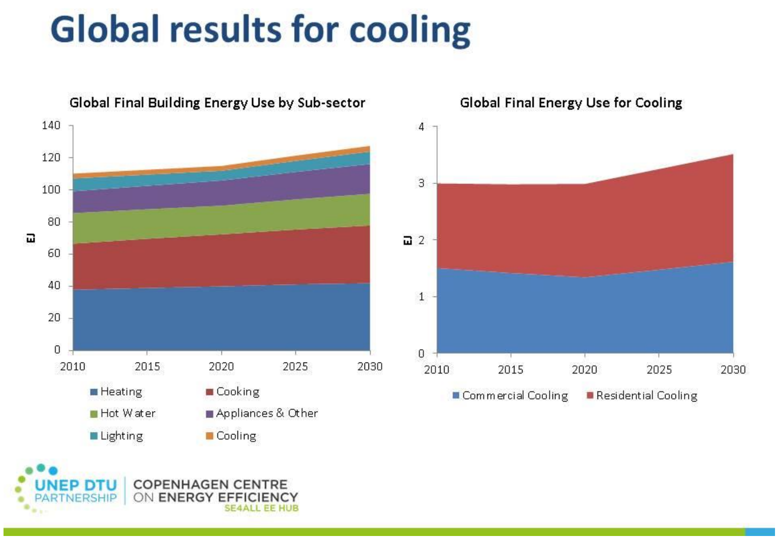
In this session there are four presentations.

Energy demand for space cooling in the context of SE4All objectives

Ksenia Petrichenko, UNEP DTU Partnership (UDP)

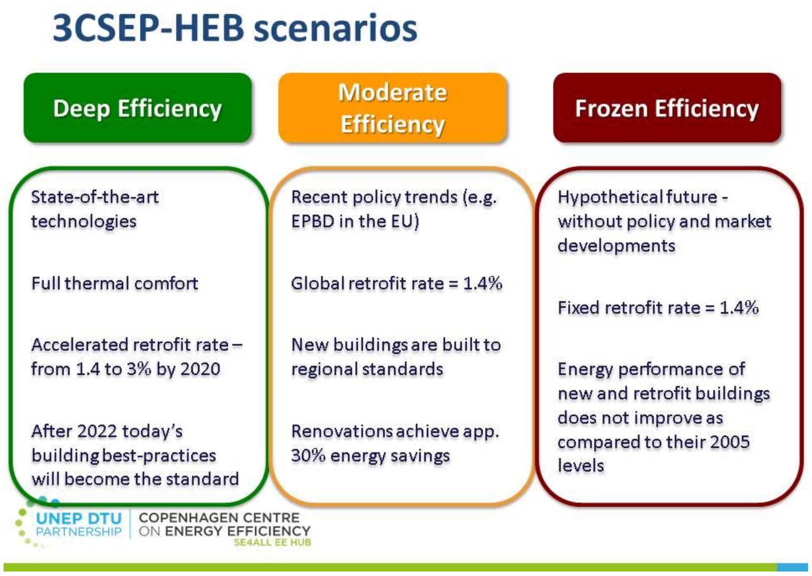
- *Link to presentation slides: Not available*

The following topics were discussed: Energy use for cooling in the global ETSAP-TIAM model, energy use for cooling in the bottom-up performance-based model and a discussion on the role of assumptions in obtaining the results.



The goal of the institute is achieving sustainable energy for all by 2030 expressed as the SE4All Objectives. To achieve this we would need a doubling global rate of improvement of energy efficiency. UDP uses the ETSAP-Tiam model. This model takes the entire energy system in account, as well as hundreds of technologies. It looks at the least cost solutions and takes exogenous constraints in account.

The results are as such fact based, and show the same trends as predicted by the IEA. The exact outcome is slightly different. This is no surprise as the SE4All project has the possibility to put much more data in the model.



The model makes is also possible to look at regional development of energy use for cooling. The USA and Canada use most energy. Although the use is currently declining due to greater efficiency, it is predicted that the use will grow rapidly in this region. The other area with a predicted fast growth is China.

The second model presented to discuss the cooling demand and options for more energy efficiency is the 3CSEP-HEB model. Three scenarios based on this model are presented.

The demand drivers in the building sector are: population, floor area per capita and floor area/capita growth in developing countries to OECD level. In the commercial sector the drivers are GDP, ccommercial floor area in the base year and commercial floor area /GDP growth in developing countries to OECD level.

Based on this model the areas with increasing energy use caused by cooling demand until 2030 are Latin America, Africa, Middle East and South East Asia. The rest of the world will see a small decline of energy use for cooling. In conclusion, "Regardless of the assumption cooling energy use will continue to grow".

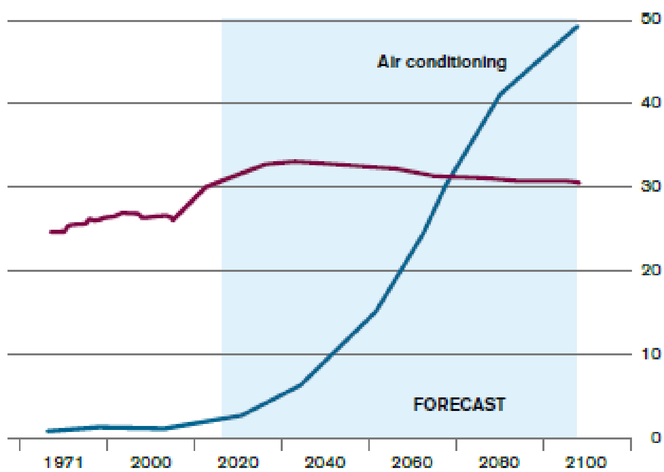
Cold energy in an integrated system

Gavin Harper, Energy Development Manager, Birmingham University, Energy Institute

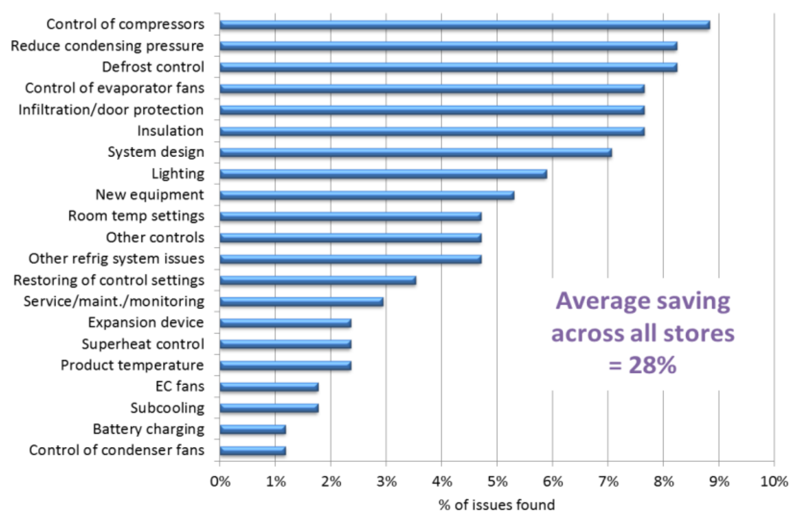
- Link to presentation slides: https://www.iea.org/media/workshops/2016/egrdspacecooling/3.GavinHarper.pdf

Air conditioning and food refrigeration are discussed, based on the report Doing Cold Smarter of the Energy Institute.

The consumption of air conditioning is to grow by factor of 30 by 2100. The US use as much electricity on air conditioning as the total energy consumption of Africa. The air conditioning makes up 40% of total electricity use in Mumbai. In UK it is relatively minor with approximately 15%. The IPCC estimates that demand will rise to 4,000 TWh in 2050 about 10 times the UK electricity bill. In 2010, Chinese consumers bought 50 million air conditioning units, in this rate they are closing in on the current domestic air conditioning fleet of the USA.



Based on all these data, the forecast for air-conditioning growth is illustrated by the graph in this text. The efficiency of air-conditioners differs a lot. On average the coefficient of performance of the appliances is in Europe 3.1, In Japan 4.8, although there is a large even more efficient group with a COP of around 6.2. So the technical possibilities are already there to be much more efficient.



According to the Birmingham Energy Institute, 10% of the global CO_2 emissions are associated with refrigeration and air conditioning. This is greater than aviation and shipping combined. There is a need to focus on refrigerant leaks.

Concerning food refrigeration about one third of food is wasted between harvest and home – much due to imperfect refrigeration. One of the problems is supermarket equipment buyers focussing on capital cost and not Life Cycle Cost (LCC). If the best in class equipment is used, efficiency could improve by 30%. There is a need to put doors on refrigeration cabinets as standard. Based on LCC and best in class equipment, doubling the UK efficiency could save the UK £1b. The different efficiency options for refrigiration in stores are also presented.

Based on the potential for UK saving of £1b, the estimated value of the cold technology worldwide is £40-110b. There is also opportunity for UK business to bring innovative technology to the international market. UK has a leading cryogenic sector (e.g. Liquid Helium technology) which could contribute to improvements of GWP of refrigerant gases. We also have to study cold energy systems approach and a better planning and integration. Use of peak demand time energy to generate cold and cooling could be another saving but would need storage.

To achieve this there are challenges within the UK context. Funding R&D is important, 70% for R&D comes from EPSRC, of the total EPSRC fund 0.2% goes to cooling; innovate UK funds about 0.1% of the projects. If UK wants to take advantage of international markets then there is need for an innovation pipeline. The funding has to be part of the interventions strategy 2015 – 2030, described in the figure below.

Interventions	Development of cold and cooling as a product; move from technology focus
	Create appropriate incentives and regulatory framework
	Introduction of market mechanisms that allow new technologies to break through
	Small and large scale demonstration facilities for proof of principle and validation
	Manufacturing environment to accelerate price competitive technologies to market
	Explotation of state-of-the-art manufacturing processes and data
	Develop a service culture and infrastructure related to cold technologies
	Development of R&D capability on a scale which matches potential of cold
	Develop@ UK skills base linked to state-of-the-art cold systems

These interventions are part of the presented UK technology roadmap for cooling, which also include collaboration between industry and the research institutes on cooling RDD&D.

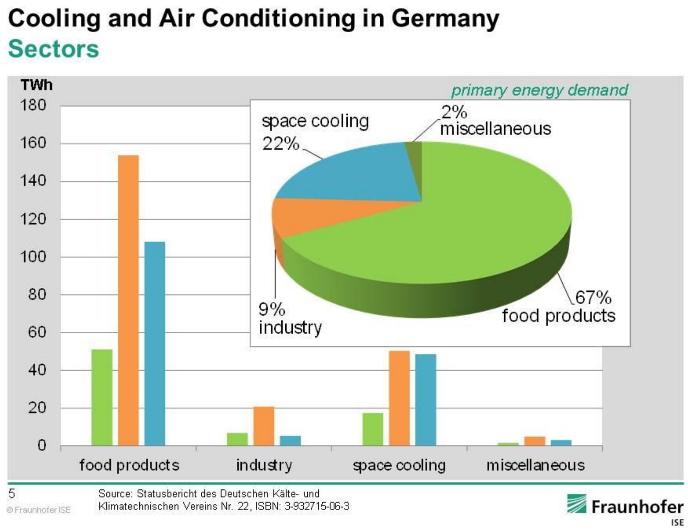
Energy demand for space cooling in Germany

Doreen Kalz, Fraunhofer Institute for Solar Energy Systems ISE Freiburg

- Link to presentation slides: https://www.iea.org/media/workshops/2016/egrdspacecooling/4.DoreenKalz.pdf

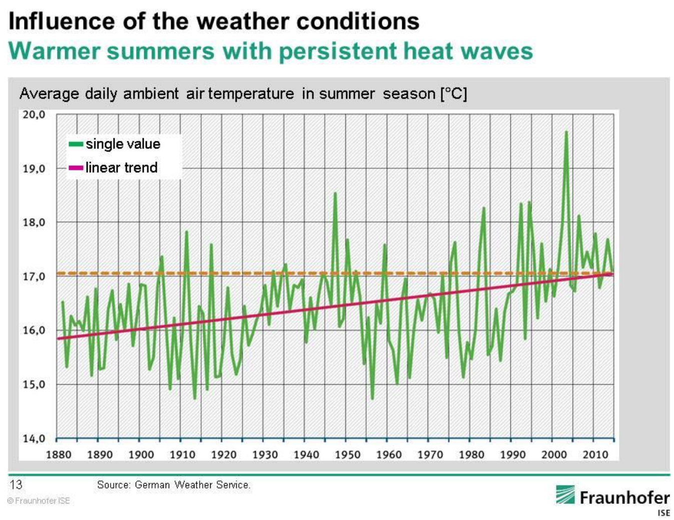
German cooling demands in the different sectors are presented, with the remark that comprehensive data are not available. Based on available data the Fraunhofer Institute develops a long term scenario, using the Primes model. A substantial rise in energy use, due to cooling demand is predicted between now and 2030.

An overview of cooling technology installed today in Germany includes chiller with piston, scroll or screw compressor have the highest share in the market.



Share of energy for cooling is low compared to the overall energy consumption, but thermal cooling demand for space cooling is increasing in both residential and commercial/service sector

These are caused by persistent heat periods in summer, heat island effect in bigger cities and elevated building standard (high quality building shell). In the modelling, historic trends over the last 135 years are used.



Requirement of user on thermal comfort is higher: individual room control, cooled spaces. Experiments on user satisfaction and expectation show that this depends on the cooling concept employed. In a comparison between air and waterbased cooling, the latter has on average a higher and more constant satisfaction.

Technologies under development are:

- Night ventilation additional to the cooling concept in use.
- The use of environmental heat sinks.
- Water-based cooling systems are now installed approximately in every second to third new construction.
- Additional requirements on cooling systems are due to “energy-flexible” buildings.

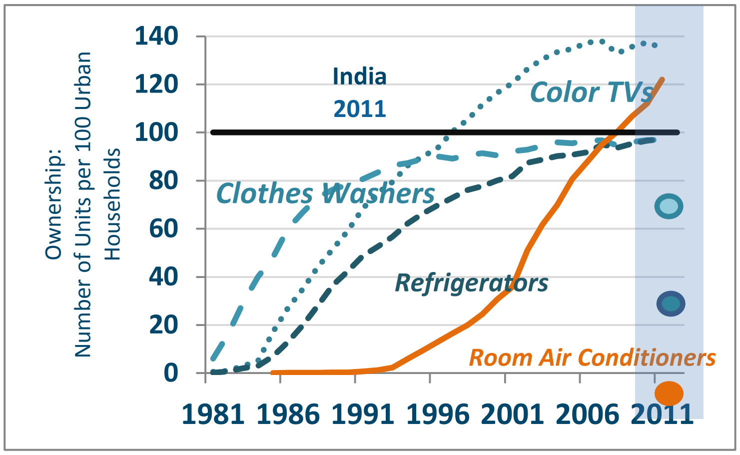
Energy demand for space cooling in a non-OECD country

Nihar Shah, researcher Lawrence Berkeley National Laboratory

- Link to presentation slides: https://www.iea.org/media/workshops/2016/egrdspacecooling/5.NiharShah.pdf
- For more information and references mentioned see: *Supplementary Literature*

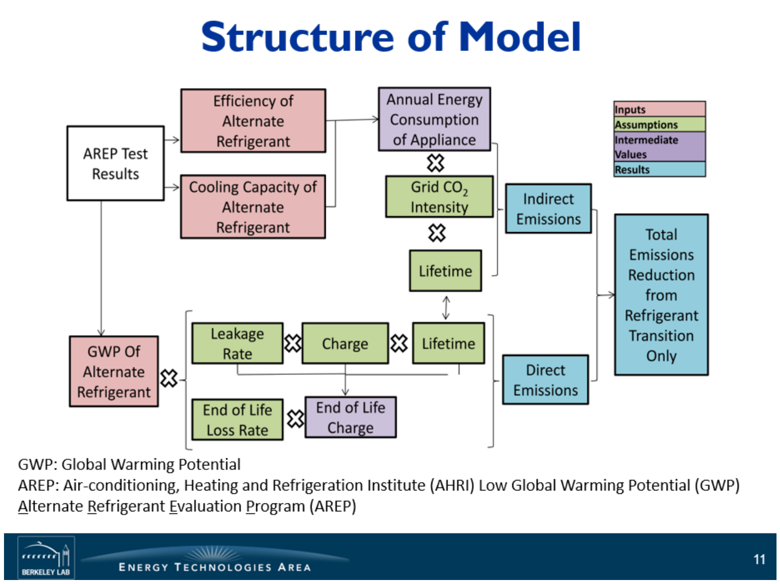
The strong growth in air cooling appliances in emerging economies has developed over a few decades:

- The air cooling equipment's ownership rate in urban China has increased from almost 0% in 1990s to over 100% in ~15 years (Fridley, 2012, 2015).
- Air conditioning sales in major emerging economies are growing at rates similar to China circa 1994–1995, e.g., India room AC sales growing at ~10-15%/year, Brazil at ~20%/year (Shah et al., 2013).



The demand for cooling differs from region to region. India, South East Asia, and Brazil all have much higher cooling needs (indicated as cooling degree days) compared to China. China today is a ~50 million/year air conditioning market, ~80 GW of connected load added per year, ~120 ACs per 100 urban households. Cooling comprises 40%–60% of summer peak load in large metropolitan cities with hot climates, such as Delhi, India, but can lead to tripling of the peak in some areas with very hot summers.

One of the topics to make cooling more sustainable is the phase-out of HFC's. Canada, Mexico the US and the Federated States of Micronesia proposed amendments[4] to the Montreal Protocol to phasedown HFCs in 2013, followed by the EU. The Montreal Protocol was seen as a successful model of international environmental treaty with financing, implementation in place and universal ratification. Large AC markets, high ambient temperatures however have concern over availability of alternate refrigerants for air-conditioning.



Shah and his colleagues have modelled the contribution of cooling to global warming. With replacement of GWP refrigerants, replacements of old models and labelling a theoretical efficiency improvement of > 50% is shown. Based on brands on the Korean market > 40% efficiency improvement is already commercial possible.

In response to environmental concerns raised by the use of high global warming potential (GWP) refrigerants, the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) has launched an industry-wide cooperative research program that identifies and evaluates alternative refrigerants for major

[4] http://conf.montreal-protocol.org/meeting/oewg/oewg-33/presession/PreSession%20Documents/OEWG-33-3E.pdf

product categories. A number of refrigerants have been tested, with good results. However some blends are also optimized for none flammability, losing some efficiency[5].

In summary, trends show significant estimated growth in the AC market particularly in major emerging economies. The increased use of air conditioning has a large impact on electricity generation and peak load, particularly in hot climates and populous countries. Efficiency improvement of ACs along with refrigerant transition roughly doubles the emissions impact rather than either policy implemented in isolation and shows significant peak load reduction.

An opportunity to maximize climate, energy and peak load benefits by designing *refrigerant transition projects* to have an efficiency improvement requirement and design *efficiency improvement projects* to have a low-GWP refrigerant requirement.

[5] This statement was challenged by Van Baxter and Omar Abdelaziz: the impact of these blend being non-flammable is on the GWP mainly. ORNL has proved that the use of A1 N40 blend as an alternative to R-404A would result in ~ 7% efficiency gain when used as a drop-in.

Summary Session 2: Technological Options to Reduce Energy Demand for Space Cooling

Herbert Greisberger, NEU

This session discusses technological options to reduce or mitigate rising energy demand for space cooling in different countries. It focusses on construction methods, the building envelope, as well as energy efficient cooling technology and devices.

Summary:

- Building design can reduce the demand for cooling considerably
- Passive cooling design is a cost efficient technology for new buildings
- Ventilative cooling can be a very energy efficient solution for both mechanical and natural systems
- High insulation and air tightness levels increase the cooling need for offices during occupied hours even in the winter season
- Hot summer (climate change) decrease the potential for passive cooling and ventilative cooling systems
- Nevertheless both technologies can reduce the energy demand for cooling substantially
- Demand side management can help to avoid peak load by thermal storage, as best practice examples have proven
- Financial incentives are needed to profit from the potential
- Beside current technologies (esp. Vapour Compression with ground, air or water as source, Heat Activated and Integrated heat pump), future technologies (adsorption heat pump, thermos-elastic or membrane cooling systems) will be developed and available in near term
- Future technologies can reduce the energy demand for cooling substantially
- Solar cooling is match the peak of solar radiation and demand for cooling
- Solar cooling is a proven technology used globally
- Passive cooling, ventilative cooling as well as solar cooling are able to avoid a substantial increase in energy demand for cooling; demand side management helps to avoid peak load and improve the integration of renewable energy from solar and wind

This session comprises five presentations.

Current and future technologies for space cooling

Van D. Baxter & Omar Abdelaziz, Oak Ridge National Laboratory

- *Link to presentation slides:* *https://www.iea.org/media/workshops/2016/egrdspacecooling/7.VanD.Baxter.pdf*

An overview of present and future technologies are:

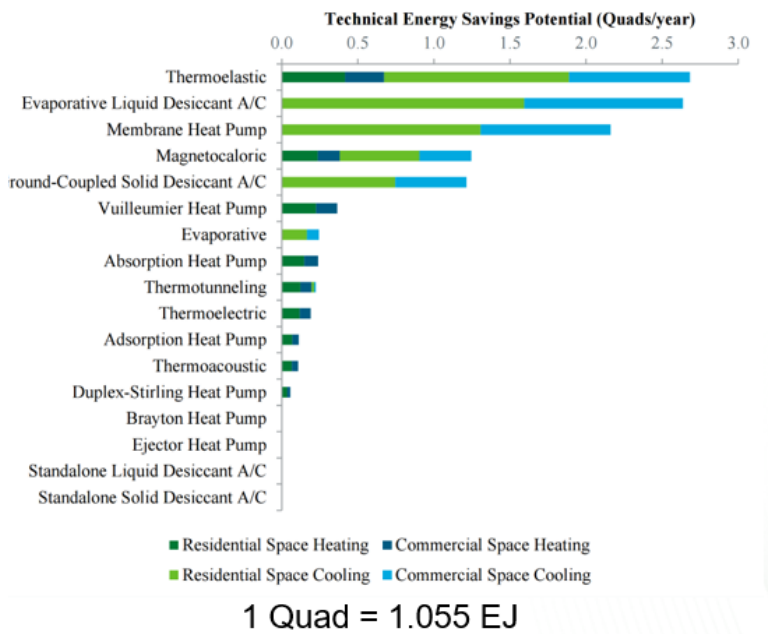
- Vapour compression using alternative lower global warming potential (GWP) refrigerants,
- Separate sensible and latent cooling systems
- Personal cooling systems
- Non-vapour compression technologies

A detailed description of the different possible technologies is presented, including the efficiency of the different systems. For the future technologies mentioned above detailed options and performance graphs are presented and discussed.

Efforts to further mitigate the environmental impact of refrigerants used in vapor compression systems have led to improvement over time:

- 1st generation "CFC" – potent ozone depleting potential (ODP) and (GWP)
- 2nd generation "HCFC" – has measurable ODP (significantly less than CFC) but potent GWP
- 3rd generation "HFC" no ODP but potent GWP
- 4th generation "HFC/HFO" blends no to extremely low ODP moderate to low GWP

Research and promotion of better refrigerants is key in this area. As major research thrusts in alternative refrigerants AHRI, the PRAHA, EGYPRA and the ORNL High Ambient Temperature (HAT) research campaign are mentioned. Alternative HVAC Technologies and their energy savings potential are presented, in combination with the use in different parts of the market (See graph). On each of the technologies an expected development time until a full-proof market product iss added, all based on the DOE Roadmap.
In order to enable R&D Initiatives it is advised to pay attention to proper system commissioning and installation with transactive HVAC management (Smart Grid). To achieve this low-cost sensors and controls and open source automation systems based on standard methods for DAS are needed. We need to demonstrate renewable-integrated district CCHP with energy recovery: buildings with simultaneous heating and cooling loads. Simplified energy analysis tools for homeowners are needed.



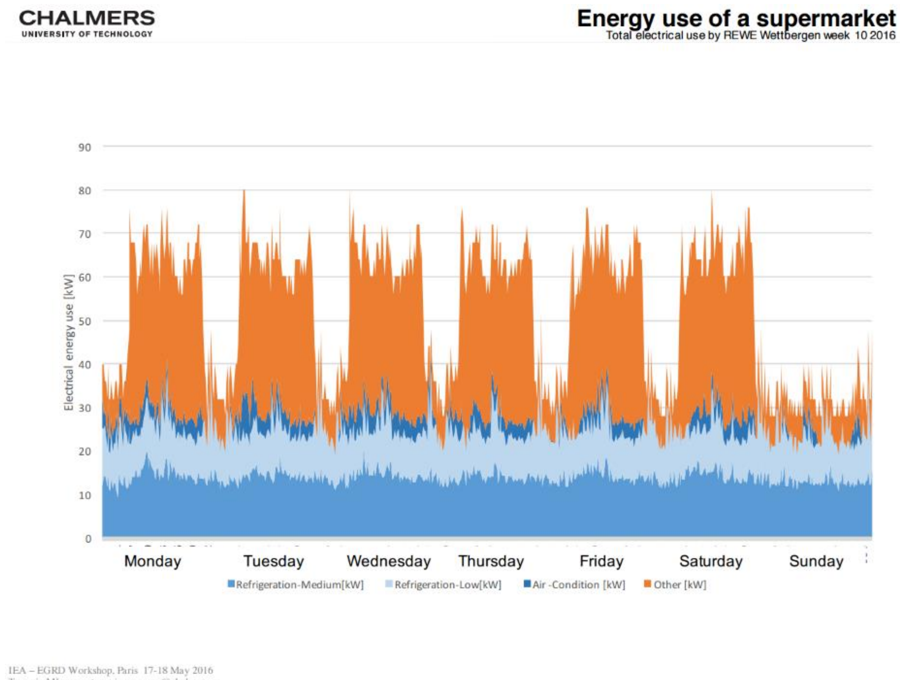
How to use cooling to avoid peak-load

Tommie Månsson, Chalmers University of Technology, Sweden

- Link to presentation slides: *https://www.iea.org/media/workshops/2016/egrdspacecooling/8.TommieMansson.pdf*

Supermarkets, their cooling needs and options is the topic of this presentation. Based on the German hourly energy consumption, and the environmental impact of energy production needed to provide for this consumption the options of supermarkets are analysed.

Supermarkets have excellent options to be more efficient, but they can also play an important role in reducing peak-load. By use of simple controls the supermarket can, within seconds, respond to a signal from a smart grid, thereby reducing the compressors electrical load. Aggregated defrosting strategies for stores are available to keep the quality of the products. The time to stop frosting has been worked out for different flexibility options.



By sub cooling the products, the compressor work can be stored and used at a later stage. An alternative is the implementation of a thermal storage tank.

Supermarkets are very suitable for peak shaving activities because of the low investment needed, the high electrical intensity and thereby the considerable aggregated impact. As they have a high refurbishment rate the newest technologies can be applied. It is possible beneficial if combined with larger cold thermal storage units to increase the flexibility from minutes to hours.

Cooling in supermarkets is a multiple scale problem. It is important to keep the energy generation in mind when designing on a component/material scale. A local decrease in efficiency could be beneficial in the larger scale.

In concluding remarks it is mentioned that financial incentives for TES in supermarkets are necessary to tap the potential. The options are adapting the demand to the spot price, which would lower the cost of energy and increasing the profit margin or a potential tax-reductions for reduced greenhouse gas emissions. A TES would be able to serve the refrigerated display cabinets for a longer period in case of compressor failure, electrical outage etc. In this way the food safety of the supermarket can be improved.

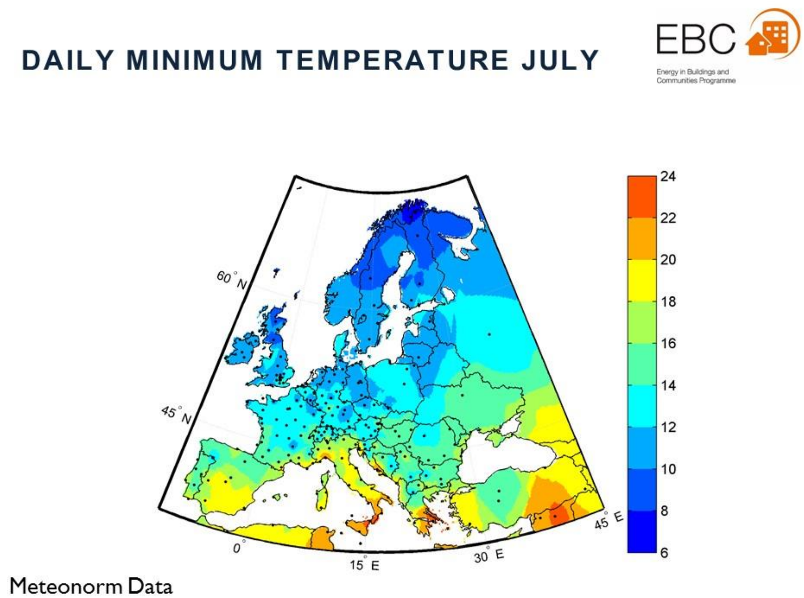
Ventilative cooling

Prof. Per Heiselberg, Aalborg University, Denmark

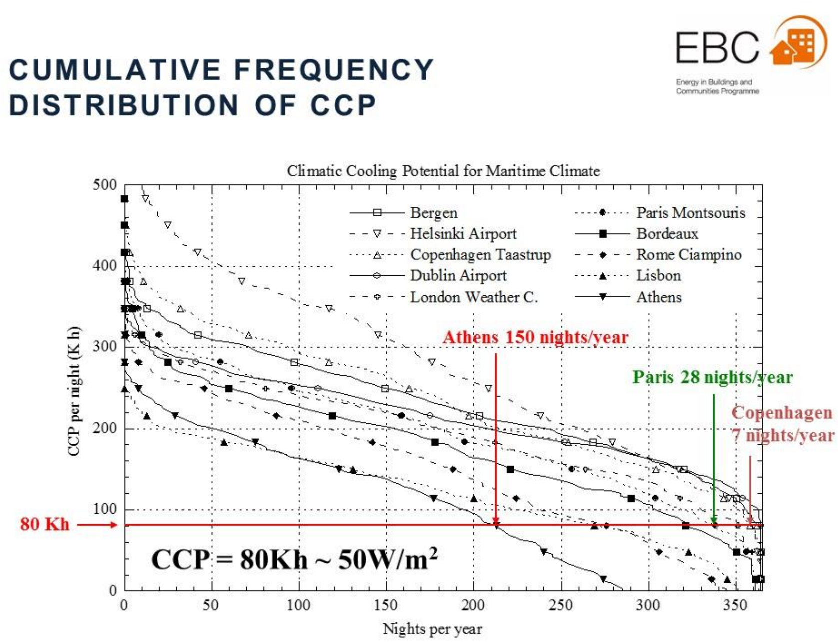
- Link to presentation slides: https://www.iea.org/media/workshops/2016/egrdspacecooling/9.PerHeiselberg.pdf

The presented work is partly done in the framework of the IEA-EBC task 62. Ventilative cooling (VC) is an application (distribution in time and space) of ventilation air flow to reduce cooling loads in buildings. VC utilizes the cooling and thermal perception potential (higher air velocities) of outdoor air. In VC the air driving force can be natural, mechanical or a combination.

VC is an attractive and energy efficient passive solution to cool buildings and avoid overheating as it is already present in most buildings through mechanical and/or natural systems. It can both remove excess heat gains as well as increase air velocities and thereby widen the thermal comfort range. The possibilities of utilizing the free cooling potential of low temperature outdoor air increases considerably as cooling becomes a need not only in the summer period.



Outdoor climate potential: as outdoor temperature is lower than the thermal comfort limit in most part of the year in many locations, and especially night temperatures are below comfort limits, natural systems can provide “zero” energy cooling in many buildings. But there are limitations. Temperature increase due to climate change might reduce potential and peak summer conditions and periods with high humidity reduce the applicability. An urban location might reduce the cooling potential (heat island) as well as natural driving forces (higher temperature and lower wind speed). High energy use for air transport limits the potential for use of mechanical systems. Also building design, fire regulations, security are issues that might decrease the potential use of natural systems.



The degree hours method to quantify the climatic cooling potential is explained. Based on cooling potential and the temperature degree days in several areas, a climate cooling potential for several parts of Europe can be calculated.

It is concluded that with high insulation and air tightness levels there is always a cooling need during occupied hours even in the winter season. Cooling is not a new technology, but the need for cooling is increasing and more efficient systems have to be developed to fulfill future energy requirements.

Application of the free cooling potential of outdoor air is widely used in mechanical ventilation systems, but high air flow rates are needed in winter because of draught risk leading to relatively high energy use for air transport.

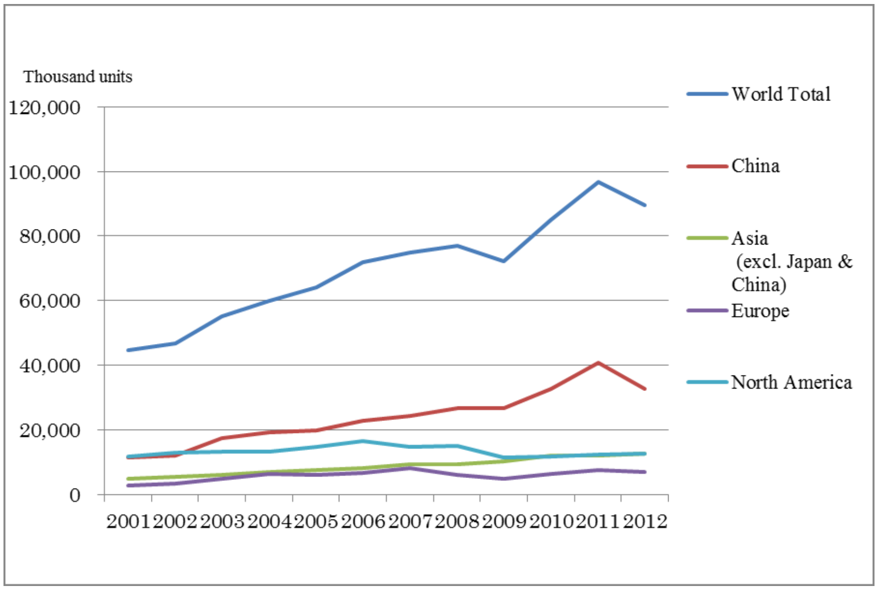
Based on the theory a number of solutions within buildings are presented end discussed.

In summary, ventilative cooling can be a very energy efficient solution for both mechanical and natural systems. Climate and building adapted solutions are essential for optimal performance; even if high summer temperatures might decrease potential in summer, development towards “near” zero energy buildings with a cooling need all year will increase the potential considerably. Solutions for cold air supply will increase potential for both mechanical and natural systems in cold climates. Integration and control of ventilative cooling in relation to other passive cooling measures as mechanical cooling solutions and user practices are essential for optimum performance in relation to energy use and comfort.

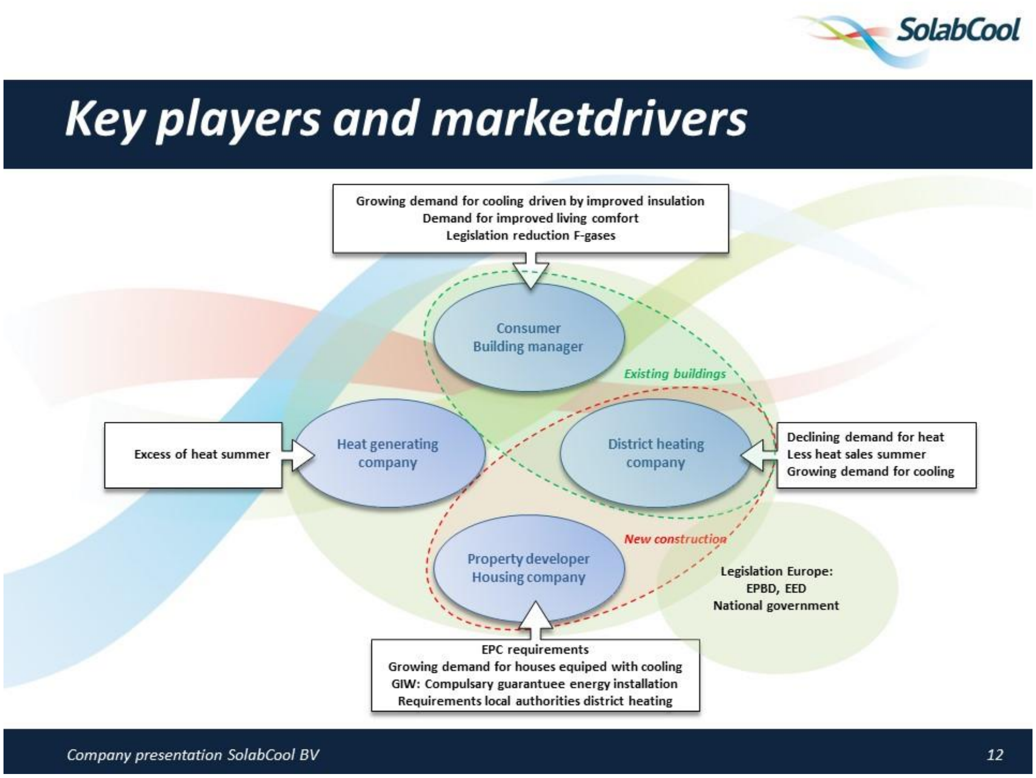
Cooling and urban energy projects

Henk de Beijer, SolabCool

Link to presentation slides:
https://www.iea.org/media/workshops/2016/egrdspacecooling/10.HenkDeBeijer.pdf



For SolabCool, cooling is business - cooling is a must. They see shifts in comfort culture, behavioural patterns, affordability and consumer expectation. It is the perception that comfort cooling contributes to higher productivity. Cooling has a direct impact on rental value of commercial buildings. The cooling need increases with internal loads (computers etc.). It is a business as >10% of electricity used for cooling (global, 16% in USA), > 80% of commercial and institutional buildings in USA and Japan have air conditioning and < 40% in EU, but expanding rapidly, 60% are expected by 2018.



The turnover of the global market for absorption chillers - or chillers - by 2020 is expected to be **983 million** US $. This turnover is favored by high environmental standards and the increasing demand for energy-efficient cooling systems (Year 2016).

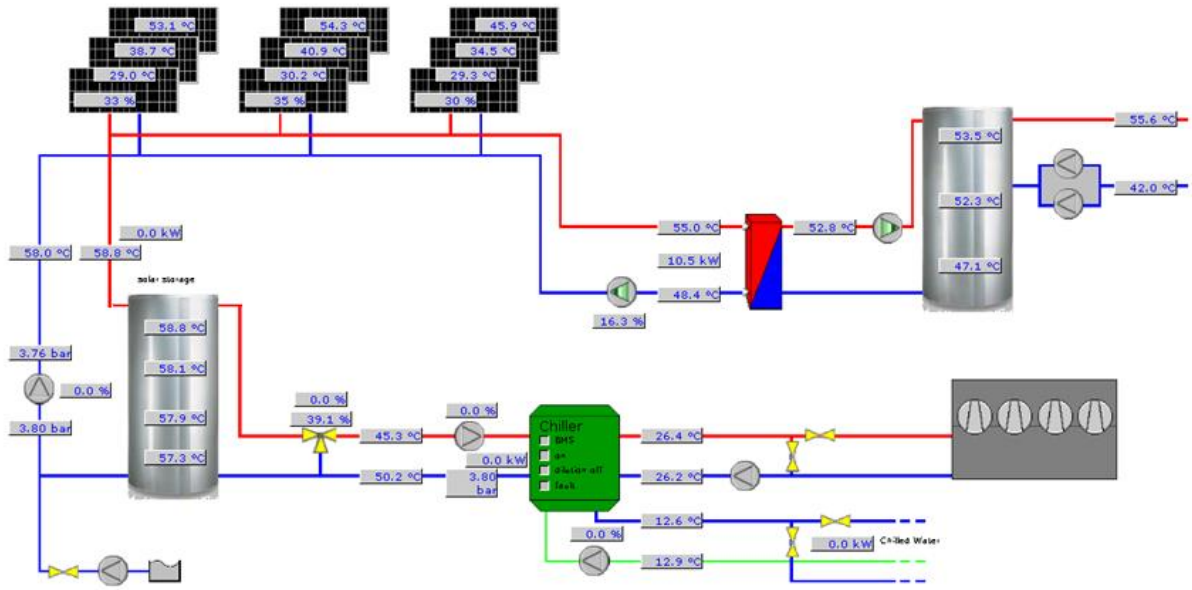
Analysis of key players and market drivers shows that solutions have to be tailor made. Sometimes a single house or even single room cooling option is the most efficient option, in other situations a district system can be more effective. A good example of an effective large scale cooling project based on renewable energy is the *Solar island District Heating "Almere"* project with 7000 m^2.

To illustrate the above a number of technologies are presented, each time with graphs showing the optimal use of the technology in question.

As example of an effective district system is the cooling office building incineration plant " Afvalverwerking Rijnmond" (AVR). The benefits of the incineration plant are plural: optimal use of excess heat, up to 90% reduction of electricity use compared to conventional air conditioning, improved return heat grids due to heat sales summer and up to 90% CO_2 reduction depending on heat source. Furthermore, there is an easy integration with the existing system heat/cold distribution and a limited maintenance and long lifetime.

Large solar thermal energy systems for cooling and heating
Harald Blazek, S.O.L.I.D

- Link to the presentation: https://www.iea.org/media/workshops/2016/egrdspacecooling/11.HaraldBlazek.pdf



The global energy consumption for cooling is higher than all global energy consumption for heating. Electricity consumption shows extreme peaks in hot climate where more than 75% of electricity is used for air conditioning (AC) today. As the building sector accounts for 42% of global electricity consumption (IEA 2007) and AC represents the biggest single energy/power consumer in public and commercial sectors. AC is further a key driver for electric peak power demand growth with a negative impact on grid load factor, electricity price and environment. It causes tremendous challenges for the future.

The S.O.L.I.D. group has started its first Large Scale Solar Cooling project 13 years ago. Looking back to a number of 17 realized systems, S.O.L.I.D. today clearly focuses on large systems for air conditioning purposes all over the globe. The utilization of Lithium-Bromide absorption chillers and special large flat plate collectors (up to 13 m² as standard size) has become the standard for a technology that has proven its performance all over the world.

The advantage of solar cooling is, that the peak of solar radiation and peak of cooling demand match perfectly during the day. The same radiation that creates the peak can be used to cover the cooling demand. On top of that, buildings can profit from shading by collectors. It avoids electricity peaks and extreme operations on the electric distribution grid; thereby solar cooling saves the most expensive electricity.

Many of the systems are running in a combined mode, serving heating and cooling loads of the different customers.

In 2014, world‘s largest solar cooling project with 4.865 m² collector area, located at the Desert Mountain High School in Arizona, USA, was commissioned. The 1.75 MW absorption chiller operates at 100% capacity during the peak hours around noon. It is fed by hot water up to 100°C as driving energy. During morning and evening hours the chiller runs with heating temperatures between 65°C to 70°C and can still contribute a significant part to the building‘s cooling demand even in partial load operation. During peak hours, 1 kWh of electricity consumed provides up to 42 kWh of cooling to the building. The annual average electrical efficiency is 25 respectively 0.14 kW/ton of cooling. The system has been realized via an energy service contract. This means, the school does not pay for the investment of the system but for the energy delivered.

Figure: World's Largest Solar Cooling System at Desert Mountain High School, Phoenix, AZ, USA.

Chiller: 500 tons / 1,750 kW, Collector area: 52,400 ft² / 4,865 m²,
commissioned 2014, project realized as a "Sale of Energy" deal.

The solar thermal system at the Desert Mountain High School causes a reduction in the consumption of electricity for air conditioning of around 90%. The whole system is operating with pure water and lithium bromide salt. With an ozone depletion potential (ODP) of zero it proves the importance for climate protection.

Solar cooling technology as a low carbon energy solution with no combustion process helps to reduce CO_2 emissions for reaching the targets for climate change. Solar thermal energy solutions for heating and cooling are proven worldwide in all climate zones and have a typical lifespan of > 25 years.

Summary Session 3: Barriers to and Supporting Factors for Low Energy Demand for Space Cooling

Robert Marlay, US Department of Energy

This session looks at the barriers and supporting factors. Input is given from policy side, both on national and local level. From industry side it is shown that barriers can be overcome and large scale cooling project based on renewable energy have been established and there is more in the pipeline.

The theoretical approach of space cooling is presented from the side of Chinese academia.

There are four presentations in this session.

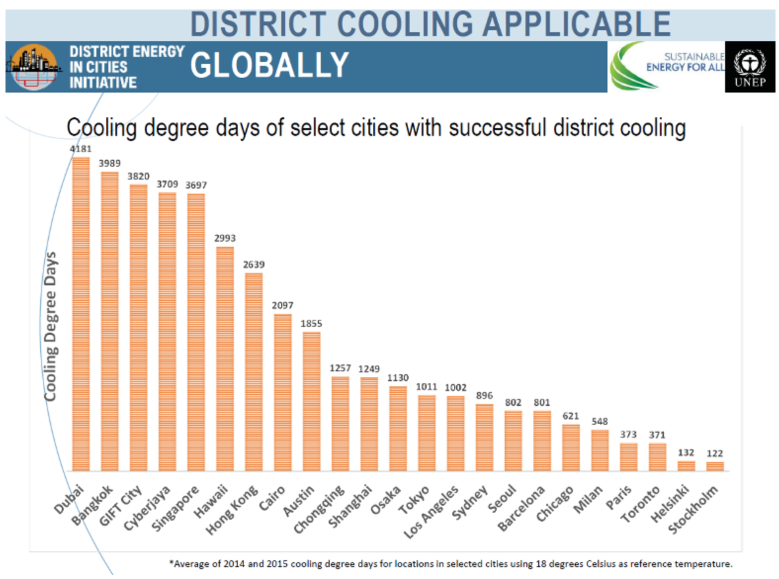
District energy in cities initiative

Djaheezah Subratty UNEP

- Link to the presentation: https://www.iea.org/media/workshops/2016/egrdspacecooling/12.DjaheezahSubratty.pdf

Based on the Climate Summit in 2014, the goal of the District Energy in Cities Initiative is to double global rate of improvement of energy efficiency by 2030. A report on District Energy in 2015 has been published by the initiative.

The initiative has both public and private partners.



To achieve the efficiency improvement a set of goals has been made. First one has to increase the knowledge of multiple benefits to promote district energy. Then the viability of district energy and the development of city-wide policy-investment plans have to be demonstrated. Scaling up district energy in cities by replicating best practice is the next step. This can only be done if we create an environment that favours investment in district energy.

Significant barriers to district energy development are numerous. Among them are the lack of awareness and misperceptions, lack of local and institutional capacity for coordinating District Energy Systems (DES) development, as well as the lack of holistic planning policies that integrate energy and DES. Incentives and accounting methods that are not harmonized are also barriers in combination with commercial viability of DES unproven in some markets. And as illustrated in previous presentations, there is a lack of data on cooling consumption.

The objectives, strategy and targets of local governments include integrated energy planning, holistic urban planning and catalysing network development as well as connecting policies.

Cities need to assess and demonstrate the benefits of district cooling in the context of local objectives and its potential. Long-term development of district cooling requires its incorporation into local energy strategy and targets. Advantages of this approach are derived from the results of 45 "Champion" Cities.

Holistic urban planning and district cooling is demonstrated with three projects in Tokyo, Hong-Kong and Singapore. To ensure cost-effective district cooling, cities need to analyse the interaction between energy, land use and infrastructure – including power, waste, water, buildings and transport. These analyses have to include energy planning integrated into infrastructure development; expert planning authority to create optimal conditions for district cooling: mixed use zoning and compact land use and designated zones to apply tailored policies or financial incentives for district energy. City action in this urban planning is to ensure that opportunity areas are zoned as mixed-use, ensure that opportunity areas have a high allowable building density and establish anchor loads in or adjacent to opportunity areas *(hospitals, malls, leisure centres, government buildings…)*

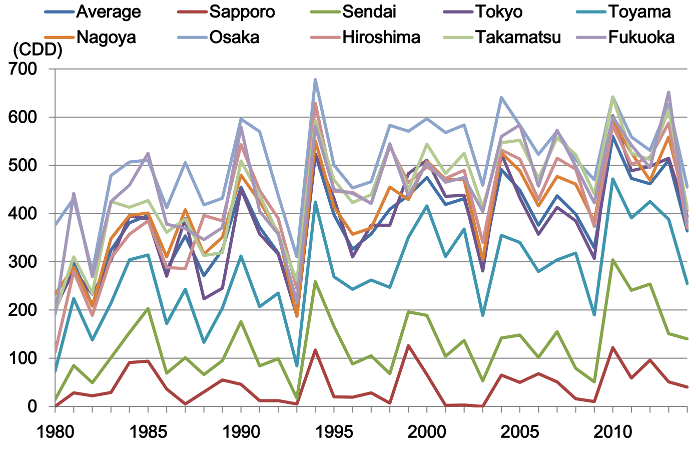
Targeted incentives used by cities include connection to district cooling, density bonuses, subsidies for connection and credit towards green building certification.
Building compatibility requirements can include centralized cooling systems

Cooling energy: Demand, technology and institution

Atsushi Kurosawa, IAE Japan.

- Link to the presentation:
  https://www.iea.org/media/workshops/2016/egrdspacecooling/14.AtsushiKurosawa.pdf

An Energy Intensity and Activity Index for both commercial and residential buildings has been developed. Ever since the year 2000 there is an overall declining energy use in Japan, even in cooling. Still there are large differences among regions. Urbanization would accelerate heat island effects in some regions. Also there is inter-annual variability between peak years and off-peak years.



The top runner labelling programme is important for the decline in energy use. It is a mandatory program from 1999. It encourages competition among companies by setting the efficiency targets for the next 3 to 10 years. The program has contributed to the significant energy efficiency improvement. Building materials are added recently to the top runner program.

Japan has started energy labelling for manufacturers and retailers in 2006. This scheme covers most of top runner products.

Envelope requirements of building energy conservation are important to reduce energy demand (both cooling and heating). New legislation covers both residential and non-residential buildings. This scheme is called BELS (Building-housing Energy-efficiency Labelling System) and will be enforced when a new law will be effective from April 2016 and full operation from 2017. The law foresees obligation, notification and efforts that have to be undertaken (category dependent).

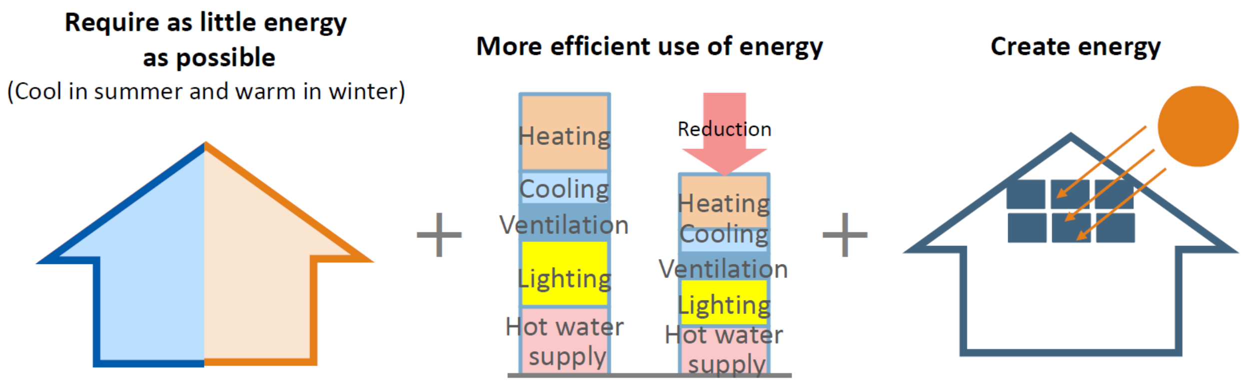
International collaboration is done with special focus on Asia. . The goal is capacity building of energy efficient equipment performance tests and industrial standard with Asian countries. Energy efficiency performance evaluation in the product standards (i.e. ISO and IEC) are performed in collaboration with China, India, Indonesia, Korea, Malaysia, Philippines, Singapore, Thailand, Vietnam. Product coverage of this work includes air-conditioner, refrigerator, LED, building material, etc.

Air conditioners are one of important target products. Japan submitted an ISO new work item proposal. A new ISO 16358 has been published in 2013, which includes testing and rating methods of high efficient inverter-type air conditioner.

All measures combined Japan is working on the concepts of ZEB (Net zero energy building) and ZEH (Net zero energy houses). ZEB is a building with considerably reduced annual energy consumption by saving as much energy as possible via better heat insulation, solar shading, natural energy and high-efficiency equipment as well as creating energy (e.g. photovoltaic power generation), while maintaining comfortable environments.

ZEH is a house with an annual net energy consumption around zero (or less) by saving as much energy as possible while maintaining comfortable living environment. This can be achieved through better heat insulation, high-efficiency equipment, and creating energy with photovoltaic power generation.

Both concepts, with their distinctive components and the diffusion of ZEB/ZEH are illustrated.



This includes the R&D case of a commercial building with a developed for ZEB HVAC prototype and liquid cooling for energy conservation and comfort.

In summary, there are still technological challenges and innovations are needed. These include passive technologies such as heat insulation, thin materials (e.g. vacuum insulation), a radiative self-cooling material reflecting solar radiation during days and nights in the building shell and natural lighting and/or natural ventilation adjusted to local climate and urban design. Known technologies also need attention in order to bring down the cost down of high performance appliances, such as high performance heat pumps, CHP including fuel cells, and latent heat recovery water boilers. Innovative energy management technologies also have to be further developed. Also built-in photovoltaic panels need more attention.

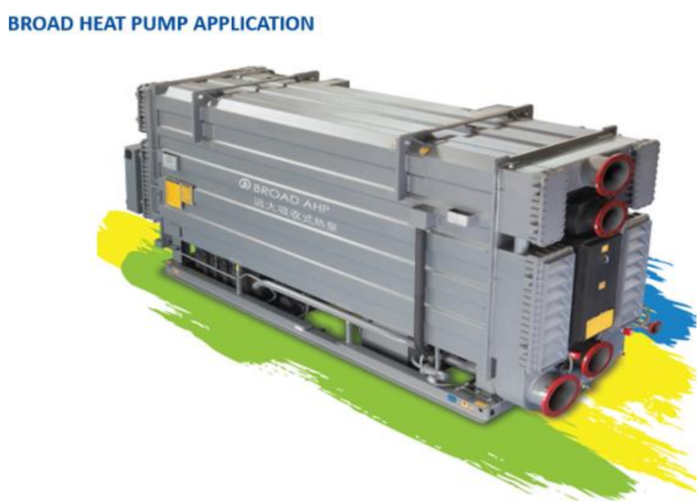
The transition to ZEB/ZEH will come with social challenges. So there is need for standardisation of energy saving technologies for buildings to assist the global diffusion of ZEBs/ZEHs. Regulation and incentives for buildings to meet energy saving standard and to integrate renewable and unused energy will be developed. These regulations must take the needs and appropriateness into account. But eventually our lifestyle has to change. We have to develop energy saving life styles with a social-scientific approach for segmented customers. This approach needs to include economic incentives.

Smart grid integration of ZEBs/ZEHs into small-scale smart grids and heat exchange systems among buildings will be necessary to realize zero emission community.

LiBr absorption chillers and heat pumps.
Hu Haidong, Broad Europe

- Link to the presentation: Not available

This presentation covered both technology introduction and sample cases around the globe. Heat pumps differs widely from water pumps: Water pumps use external power to move the water from LOW position to HIGH position, Heat pumps use external power to move the heat from LOW position to HIGH position.

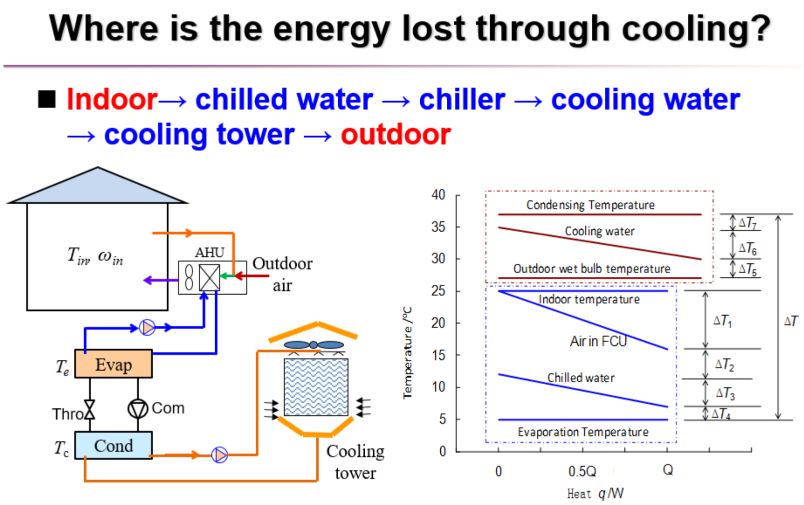


Also a number of BROAD technology case studies are presented with, among others, CCHP hot water type, steam heat pump and some distributed energy systems.

Reducing cooling energy by system innovation
Yi Jiang, Operating agent EBC Annex 59, Building Energy Research Center, Tsinghua University

- Link to presentation: https://www.iea.org/media/workshops/2016/egrdspacecooling/16.YiJiang.pdf

An important topic is the question where is the energy lost through cooling? The real demand for space cooling is just like raising the heat Q (Volume) for 3°C from 25 °C indoor to 28 °C outdoor. The required work is in that case 3Q [WK]

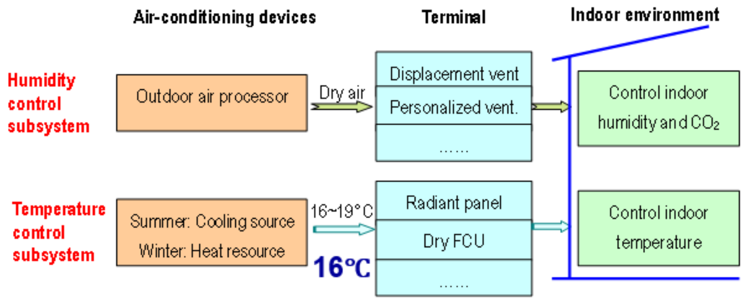


However, the chiller does lift up the heat Q from 5 °C at the evaporator to 40 °C at the condenser, the actual work is 35Q [WK], as many as 11 times! The additional 32Q has been paid for completing the heat transfer process as well as the heat flux mixed with different temperatures during the heat transportation process from indoor to outdoor. The other reason is that dehumidification is required. To make moisture condensate the cooling source needs a low temperature below dew point.

An innovation of space cooling system loses less energy: humidity control is separated from temperature control: THIC. In this system an independent air system is added to remove latent heat for humidity control. The temperature can then be controlled by a high temperature cooling source (e.g. 15°C to 20°C) to remove sensible heat only. As sensible heat normally takes more than 70% of the total heat load, a high efficiency cooling source can be used to remove sensible heat. Some examples: underground water or underground heat exchanger can be applied if ground temperature is below 15°C, evaporate cooling can also provide the cooling source if the dew point outdoor is below 15°C; a COP of 9 ~ 10 can be achieved with a compression chiller, compared with the COP of 5~6 of a normal state.

In order to get high efficiency one has to reduce the temperature difference between indoor space and cooling source so to raise required cooling source temperatures as high as possible and has to reduce the power of fans and pumps by improvement of the heat delivering system.

Sensible heat removal for temperature control saves energy. In more than 40% of cooling applications in the world the outdoor dew point is below 15°C. Moisture can be removed by air exchange with outdoor. Space cooling is just to remove sensible heat.



Operating principle of the THIC air-conditioning system

To raise the cooling source

temperature for high efficiency cooling, the key approach is to reduce the Δt during heat delivering process, thereby avoiding the mixing loss of heat collection process at indoor terminals, Δt loss of heat exchange process and the mixing loss of heat fluxes with different temperature

To avoid the Δt loss of heat exchange process, there has to be direct connection of the cooling source with indoor terminals and one has to enlarge the heat transfer ability and adjust the flow rates at both sides so to ensure the Δt uniformed along the heat exchange process. There has to be a 4~5 K temperature difference for water circulation and an on-off control for each indoor terminal (radiative) to obtain near linear control performance. A careful design of the water piping system to avoid large pump power consumption.

Efficient dehumidification process in moist region is not easy and that is why humidity control is part of the task in space cooling. This requires the cooling source below dew point with reheat, or mix with higher temperature environment. New approaches for dehumidification are required!

The conclusion is that there is a huge potential saving in space cooling technology.
In dry regions, ~40% of current cooling applications, direct/indirect evaporative cooling instead of mechanical chillers system should be well designed both for indoor terminal and heat delivering to adapt "high temperature cooling". With this technology more than 50% energy can be saved.
In regions with a moist climate like East China and US, Japan and South India humidity should be treated independently with temperature. Desiccant humidity control techniques should be applied for dehumidification, sensible heat should be removed with high temperature cooling source. Then about 30% saving can be achieved.

Summary Session 4: Public Policies Toward Space Cooling

Atsushi Kurosawa, IAE

This session explores policy issues of cooling technologies. Public policy support from the view of institution and R&D is essential especially in early stage technologies. EU directives in energy efficiency policy packages aim at comprehensive approach covering most energy sectors including building cooling, district cooling, integrated planning. Mission Innovation (MI) is a new global initiative established in December 2015 aiming at energy innovation acceleration through doubling public R&D investment, leveraged by private sector support. MI and US. energy R&D budget prospects are presented. IEA pointed out growing concern in cooling, and breaks down energy efficiency improvement of cooling energy into two factors (need and energy-used). This implies importance both in building envelope and equipment, technical and political approaches.

In this session there are three presentations.

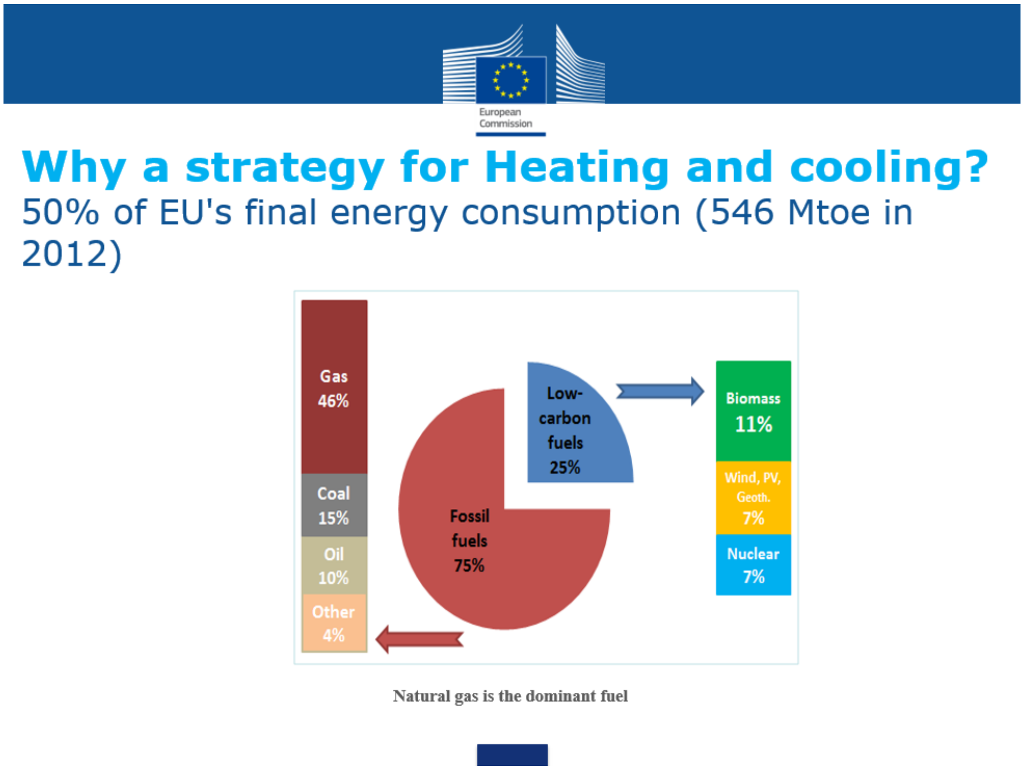
Energy efficiency in space cooling

Timothée Noël, EACI, European Commission

- Link to the presentation: https://www.iea.org/media/workshops/2016/egrdspacecooling/17.Timoth%C3%A9eNo%C3%ABl.pdf

EU adopted the security of supply package on 16 February 2016. It includes communication document Heating and Cooling Strategy (COM (2016) 51 final).

EU strategy for heating and cooling is one of the actions under the Energy Union Strategic Framework and Roadmap of 25 February 2015. It outlines how to integrate EU energy policies, focusing on buildings, industry and integrated approach (i.e. energy savings with renewables supply, heating and cooling with electricity systems, heating and cooling with industrial waste heat and cold).



Challenges and barriers in buildings, industry, district heating and cooling, cooling, waste heat and cold, CHP, storage are identified. They are incentives, human resources, finance, institution, data, business models, market integration, etc. Follow-up actions are summarized in terms of legislative review, intensified implementation, non-legislative actions, intensification of current non-legislative actions Industrial round tables, innovation support.

Work on legislative proposals including impact assessment, expected in early autumn 2016 for EU Energy Efficiency Directive (EED), Energy Performance of Buildings Directive (EPBD), and Eco-design and energy labelling framework, are major activities directly related cooling to institution applied for EU level.

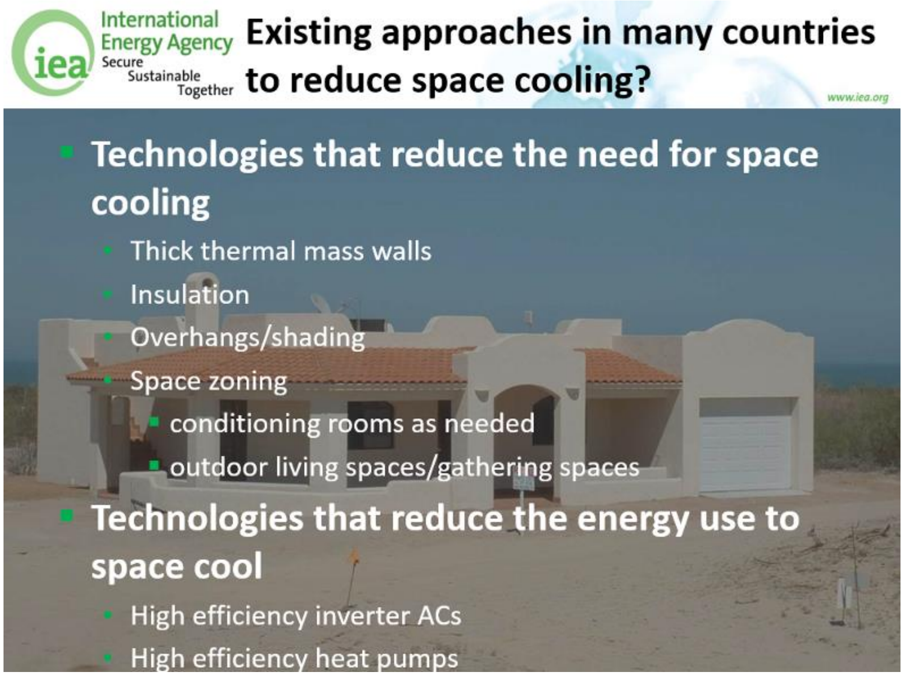
IEA global policies

Brian Dean, IEA

- Link the presentation: https://www.iea.org/media/workshops/2016/egrdspacecooling/18.BrianDean.pdf

Energy demand for space cooling will grow due to changes in wealth & comfort, population, climate conditions, construction practices and electronics usage. This tendency is also applied to Mexico, focusing country of World Energy Outlook 2016.

Requirements for both need and energy reduction for space cooling are pointed out. Policies for need reductions are building related institutions, incentive for envelope technologies, capacity building. While energy reduction policies are equipment performance standards, equipment labelling, subsidies/tax incentives and capacity building.



There are technology opportunities for need reduction such as insulation materials, airflow, shading, roof and reflective materials. Equipment and district level energy reduction technologies are available also.

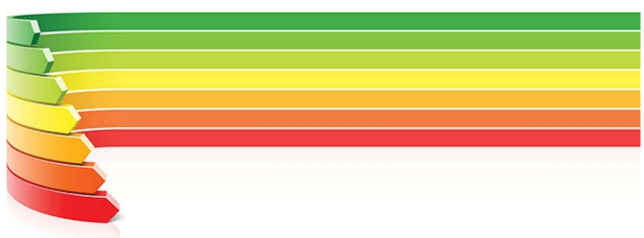
The key focus areas for IEA research are buildings (residential, tertiary) where attention is on renovation and deployment of efficient, sustainable supply (renewables, waste heat/cold); industry (energy intensive sectors, all enterprises, SMEs) where energy efficiency and renewable energy are the first steps before recovery of waste heat & cold. Overall IEA looks at three key synergies (comprehensive integrated approach):

- Linking energy savings with the deployment of sustainable (renewable-based, low carbon) supply;
- Linking heating & cooling with the electricity systems;
- Linking heating & cooling of buildings with industry for the use of waste heat and waste cold.

The IEA encounters a number of challenges and barriers. The most important ones are:

- In buildings we are faced with Split incentives in condominiums and owner-tenant relationships, lack of information-knowledge-expertise, lack of trained professionals, lack of capacity in national (local) authorities, financing (bundling, investibility).
- In industry there is a lack of information-knowledge-expertise, lack of trained professionals, financing (lack of accounting for benefits).
- District heating & cooling is a potential instrument of decarbonisation, but it has a negative image from some old legacy systems, and again there is a lack of capacity of national (local) authorities to develop it (energy planning and heat mapping), financing.
- In cooling there is an overall lack of data, while it is a new fast growing area.
- Waste heat & cold are more faced with a lack of capacity of national (local) authorities, a lack of business models and coordination between industrial and D & H companies and authorities. Also financing is problematic.
- CHP meets electricity market integration barriers and a lack of accounting for benefits.
- And in the end storage has to overcome the lack of regulatory framework.

The next steps of the EU are legislative reviews of the EU Energy Efficiency framework (Energy Efficiency Directive, Energy Performance of Buildings Directive, Eco-design and energy labelling framework), and of the Renewable Energy Directive and new electricity market design in 2016.
Already intensified implementation of the current legislation (e.g. Article 19 of the EED on split incentives) is announced, as well as new non-legislative actions (e.g. industrial round tables for energy industries). Current non-legislative actions (e.g. BUILD UP Skills, SET plan, Covenant of Mayors, etc.) will also be intensified.



Mission innovation and cooling

Robert Marley – US DOE

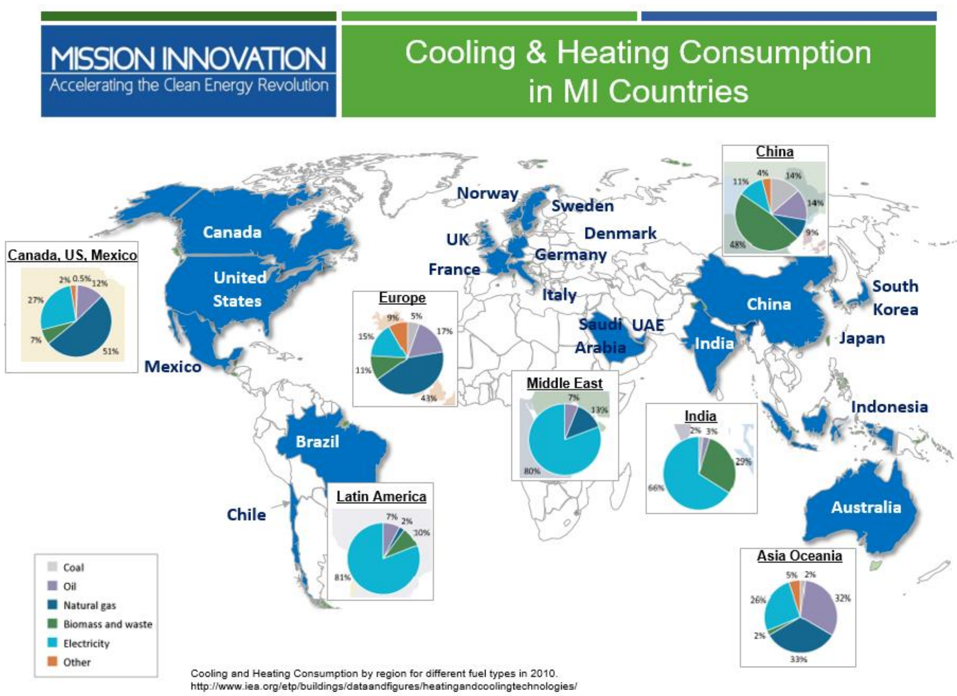
- Link to the presentation: https://www.iea.org/media/workshops/2016/egrdspacecooling/19.BobMarlay.pdf

During 21st Conference of the Party on UNFCCC (COP21) in Paris 2015, leaders of 20 countries representing 80% of global clean energy R&D investment agreed to support a Joint statement on innovation the so-called Mission Innovation, targeted doubling of government clean energy R&D over next five years complemented by private sector initiative. Its focus is future innovation and enables clean energy solution with joint effort by Clean Energy Ministerial (CEM) aiming at deployment assistance policies.

Six thematic ad hoc sub-groups are organized for MI implementation. In June 2016, Energy Ministers of MI countries meet in San Francisco, in conjunction with CEM to discuss doubling plan and other issues.

Overview of future US clean energy R&D budget commitment to meet with MI pledged action is presented. Total clean energy R&D budget DOE and other 11 agencies in FY2017 reached 7.7 billion USD. New or enhanced approaches within DOE basic and applied R&D are presented.

Cooling technology R&D portfolio in MI countries is briefly summarized



Supplementary Literature

Session 0

- IEA (2016) *Energy Technology Perspectives - Towards Sustainable Urban Energy Systems,* Paris IEA

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- Diana Urge-Vorsatz, András Reith, Katarína Korytárová, Mónika Egyed, János Dollenstein (2015) *Monetary Benefits of Ambitious Building Energy Policies*, GBPN
- Gavin Harper et.al. (2015) *Doing Cold Smarter*, University of Birmingham
- Shah, N. et al (2015) *Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning*, LBNL-1003671

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- Hickman, Ken (2013) *Reference List for low GWP Refrigerants Testing*, AHRI, Arlington VA
- Abdelaziz, O. et al (2015) *Alternative Refrigerant Evaluation For High-Ambienttemperature Environments: R-22 And R-410a Alternatives For Mini-Split Air Conditioners*, ORNL/TM-2015/536, Battelle
- EIA(2016) *Putting The Freeze On HFCs*, EIA, Washington DC
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- Riahi, Lily (2015) *District Energy in Cities*,UNEP
- Liu XH, Jiang Y, et al (2014) *Temperature and Humidity independent Control (THIC) of Air-conditioning System*. Springer Press, Berling

Session 4

- IEA (2011) *Technology Roadmap Energy-efficient Buildings: Heating and Cooling Equipment*, IEA Paris
- European Commission (2014) *A policy framework for climate and energy in the period from 2020 to 2030*, Brussels

Appendices

Appendix A - Acronyms

Acronym	Name
3CSEP HEB	Center for Climate Change and Sustainable Energy Policy High Efficiency Buildings Model
AC	Air Conditioning
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
Bells	Building-housing Energy-efficiency Labelling System
BEMS	Building Energy Management Systems
C	Celsius
CDD	Cooling Degree Days
CEM	Clean Energy Ministerial
CERT	IEA's Committee on Energy Research and Technology
CFC	chlorofluorocarbon
CHP/DHC	(IEA TCP) Combined Heat & Power(CHP/District Heating and Cooling (DHC)
COP	UN: Conference of the Parties
COP	Coefficient of Performance
DC	Direct Current
DES	District Energy Systems
DOE	U.S. Department of Energy
DTU	Technical University of Denmark
E4	Energy Efficiency in Emerging Economies programme
EBC	(IEA) Buildings and Communities (TCP)
EED	(EU) Energy Efficiency Directive
EGRD	Experts' Group on R&D Priority Setting and Evaluation
EPBD	(EU) Energy Performance of Buildings Directive
EPSRC	Engineering and Physical Sciences Research Council (UK)
ETP	(IEA's) Energy Technology Perspectives
ETSAP	Energy Technology Systems Analysis Program (TCP)
ETSAP-TIAM	ETSAP-Times Integrated Model
G20	Group of 20 (major economies)
Gton	Billion Metric Tonnes
GWH	gigawatt-hours
GWP	Global Warming Potential
HAT	High Ambient Temperature
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HVAC	heating, ventilating/ventilation, and air condition system
IAE	Institute of Applied Energy (Japan)
IEA	International Energy Agency
IPCCC	Inter-Governmental Panel on Climate Change
ISGAN	International Smart Grid Action Network
JST	Japan Science and Technology Agency
km	Kilometre(s)
kW	Kilowatt(s)

Acronym	Name
kWh	Kilowatt-Hour(s)
L	Litre(s)
LCC	Life Cycle Costs
MW	Megawatt(s)
NEDO	New Energy and Industrial Technology Development Organization
ODP	Ozone Depleting Potential
OECD	Organization for Economic Co-operation and Development
PV	Photovoltaic(s)
R&D	Research and Development
RD&D	Research, Development and Demonstration
RDDD&D	Research, Development, Demonstration, Deployment and Dissemination
RVO.nl	Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland)
TCP	Technology Collaboration Programmes
TES	Thermal Energy Storage
TWh	Terawatt-Hour(s)
UNEP	United Nations Environment Program
UNFCC	United Nations Framework Convention on Climate Change
V	Volt(s)
VC	Ventilative Cooling
ZEB	Net zero energy building
ZEH	Net zero energy houses

Appendix B - Agenda

DAY 1 – Tuesday, 17 May 2016

Introduction: Setting the Scene

The session provides background and context for the Workshop. It reminds participants of the purposed, interactive nature of presentations, dialogue and social interactions, and the expected outcomes, and post-meeting activities and communications.

- *Previous work of the group*
- *Rationale of the workshop*
- *Expected outcome of the workshop*
- *Expected demand for space cooling*
- *Activities with the IEA on space cooling*

Introduction			
Chair: Rob Kool			
08:30	*Registration*		
9.00 - 10:00	Welcome		IEA
	Introduction		Rob Kool, Chair EGRD, Netherlands Enterprise Agency
	1	Global energy demand for space cooling in 2050	John Dulac, IEA

Session 1: Future Demand for Space Cooling

This session analyses the current and projected demand for space cooling globally, as well as for selected regions of interest.

- *What do scenarios forecast for future energy demand for space cooling?*
- *What are the main drivers for increasing demand for space cooling?*
- *Which measures can be taken to stabilize the energy demand for space cooling?*
- *How is space cooling handled in different countries?*
- *How does occupant behavior relate to energy demand for space cooling?*

Future Demand for Space Cooling			
Chair: Birte Holst Jørgensen			
10:00	2	Energy demand for space cooling on regional and global levels	Ksenia Petrichenko, Researcher, Copenhagen Center on Energy Efficiency, UNEP DTU Partnership
10.30	3	UK cold energy needs in an integrated system	Dr. Gavin Harper, Birmingham Energy Institute

11:00	4	Energy demand for space cooling in Germany	Ms. Doreen Kalz, Fraunhofer ISE Institute
11:30	5	Energy demand for space cooling in a non-OECD country	Mr. Nihar Shah, Lawrence Berkeley National Lab
12:00	6	Energy demand for space cooling, best practices in Italy	Giovanni Puglisi, ENE/Solar Heating and Cooling TCP
12:30	Discussion		
13:00	*Lunch*		

Session 2: Technological Options to Reduce Energy Demand for Space Cooling

This session discusses technological options to reduce or mitigate rising energy demand for space cooling in different countries. It focusses on construction methods, the building envelope, as well as energy efficient cooling technology and devices.

- *Can the problem of growing energy demand for space cooling be solved through building design and energy efficient construction?*
- *How can demand side management help to minimize the need for space cooling?*
- *Which technologies for space cooling are currently used?*
- *What is the current status of technology for space cooling?*
- *To what extent can the energy demand be reduced by energy efficient devices?*
- *To what extent can new refrigerants contribute to reducing the problem?*
- *Can or to what extent can solar energy solve the problem?*
- *What progress can be expected in the foreseeable future?*
- *To what extent can geothermal cooling contribute to solving the problem?*
- *How can thermal energy storage systems (phase change material, ice storage) assist in shifting the cooling load for building owners and lowering the peak demand for utilities?*
- *After all energy load reducing measures are implemented, what technologies are there to assist buildings in approaching zero energy?*
- *How is thermal energy storage accommodated in heavily urban environments?*

Technological Options to Reduce Energy Demand for Space Cooling			
Chair: Herbert Greisberger			
14:00	7	Current and Future Technologies for Space Cooling	Van D. Baxter, Building Equipment Research Group, Oak Ridge National Laboratory
14:30	8	How to use cooling to avoid peak-load	Tommie Månsson, PhD Candidate, Chalmers Univ. of Technology, Sweden
15:00	9	Ventilative Cooling	Prof. Per Heiselberg, Aalborg

			University, Denmark
15.30	*Coffee break*		
16:00	10	Cooling and Urban Energy projects.	Henk de Beijer, Director Solabcool
16.30	11	World's Largest Solar Cooling Systems – experiences from 12 years of commercial solar cooling in Europe, Asia and the USA	Harald Blazek, Strategic Business Development, SOLID
17:00	Discussion		
17:30	Close Day 1		

DAY 2 - Wednesday, 18 May 2016

Session 3: Barriers to and Supporting Factors for Low Energy Demand for Space Cooling

During this session relevant factors will be discussed that can influence the demand for space cooling and how these factors, themselves, can be shaped. The role of innovation, socio-economic factors as well as public awareness, standards and labels will be discussed and highlight how these factors can contribute to keep the demand for energy low.

- *To what extent does the age of the population influence the demand?*
- *Do regulation and/or higher comfort standards influence the demand for space cooling?*
- *Does the greenhouse effect influence the demand for space cooling?*
- *Does the increase in energy efficient devices reduce the demand for space heating in offices and private households?*
- *Is there a correlation between indoor climate and labor productivity?*

Barriers and Supporting Factors for Low Energy Demand for Space Cooling			
Chair: Robert Marlay			
09:00	12	Integration of cooling from a planning and urban development perspective	Djaheezah Subratty, Head, Policy Unit, UNEP
10:00	14	Labels and standards for cooling devices	Atsushi Kurosawa, Institute of Applied Energy, Japan
10:30	*Coffee break*		
11:00	15	LiBr Absorption Chillers and Heat Pumps – technology introduction and sample cases around the globe	Mr. Hu Haidong, Senior Engineer, BROAD
11:30	16	Best practice - technology – High Temperature Cooling	Prof. Yi Jiang, Tsinghua University, Beijing
12:00	Discussion		

Session 4: Public Policies Toward Space Cooling

This session discusses how public authorities can contribute to reduce the demand for space cooling.

- *Does the regulatory framework need adjustment to lower energy demand for space cooling?*
- *How can standards and labels for buildings and cooling devices be implemented to become effective?*
- *How can R&D contribute to minimization of CO_2-emissions related to space cooling?*
- *Can replacement refrigerants contribute to reducing refrigerant Global Warming Potential?*

Public Policies Toward Space Cooling			
Chair: Atsushi Kurosawa			
13:30	17	Heating & Cooling strategy for the EU	JRC EU Commission (Speaker tbc)
14:00	18	IEA global policies (E4)	Brian Dean, IEA
14.30	*Coffee Break*		
15:00	19	Mission Innovation & Cooling	Robert Marlay, DOE
15:30	Discussion		
16:00	Wrap Up of the Workshop, Panel Discussion, and Participants Round Table		
17:00	Close Day 2		

Appendix C - Participants

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