IEA FUTURE BUILDINGS FORUM THINK TANK WORKSHOP 2017

TRANSFORMING CITIES IN HOT AND HUMID CLIMATES TOWARDS MORE EFFICIENT AND SUSTAINABLE ENERGY USE

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BUILDING AND CONSTRUCTION AUTHORITY ACADEMY

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Additional copies of this report may be obtained from:
EBC Executive Committee Support and Services Unit (ESSU)
C/o AECOM Ltd
The Colmore Building
Colmore Circus Queensway
Birmingham B4 6AT
United Kingdom
www.iea-ebc.org
essu@iea-ebc.org

Editors
Noel Chin, Principal Manager, Building and Construction Authority (BCA) and International Energy Agency Energy in Buildings and Communities (IEA EBC) Executive Committee Alternate Member for Singapore
Wong Nyuk Hien, Vice-Dean (Research), School of Design and Environment
Brian Dean, International Energy Agency (IEA)
Tan Tian Chong, Deputy Managing Director, BCA and IEA EBC Executive Committee Member for Singapore
Andreas Eckmanns, IEA EBC Executive Committee Chair and Swiss Federal Office of Energy (SFOE) Switzerland
Malcolm Orme, IEA EBC Executive Committee Secretary and AECOM

Workshop Co-Chairs
Andreas Eckmanns, IEA EBC Executive Committee Chair and SFOE Switzerland
Tan Tian Chong, Deputy Managing Director, BCA and IEA EBC Executive Committee Member for Singapore

Workshop Facilitators
(from the National University of Singapore)
Veronika Shabunko, Solar Energy Research Institute of Singapore
Sekhar Kondepudi, School of Design and Environment
Lu Yujie, School of Design and Environment
Stephen Tay, Solar Energy Research Institute of Singapore
Teo Ai Lin, Evelyn, School of Design and Environment
Chua Kian Jon, Ernest, School of Mechanical Engineering
Lee Poh Seng, School of Engineering

Workshop Secretariat Support
(BCA interns)
Javier Tan, Ng Shi Yu, Goh Xinying, Roy Sim and Ryan Toh

UWCSEA Dover Campus site visit organiser
Bharath Seshadri, ETH-FCL

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Foreword

It was a privilege to host the International Energy Agency (IEA) Future Buildings Forum (FBF) Think Tank Workshop 2017 in Singapore from 24 - 25 October 2017. When Mr Tan Tian Chong (Executive Committee Member for Singapore) attended the IEA EBC Executive Committee meeting in Sydney, Australia in November 2016 for the first time as a new contracting party to the EBC Implementing Agreement, he was excited to learn about the plans for the next Future Buildings Forum to be held in 2017 with the theme centring around "hot and humid climates". This theme resonates well with Singapore's climate, and he readily volunteered to host this FBF Workshop. This was followed by the signing of the Collaboration Agreement and a presentation of our plans to the next EBC Executive Committee meeting, held in June 2017, in London, UK.

The task to organise such an important forum was not easy, least to say, as it involves coordinating with the representatives from the various IEA buildings-related Technology Collaboration Programmes (TCPs) who are operating in different time zones. But, we were fortunate to have the advice of the EBC Executive Committee Chair, Mr Andreas Eckmanns, and an Advisory Board comprising of representatives from each of the TCPs to guide us in developing the session plan. After two productive Internet meetings with the Advisory Board, we settled on a comprehensive two-day session plan with an impressive list of renowned speakers for the plenary session to stimulate discussions at the parallel workshops.

We were privileged to have the support of the National University of Singapore (NUS) School of Design and Environment in organising this FBF Workshop. Prof Lam Khee Poh, Dean of the School kindly agreed to deliver the keynote speech, while Prof Wong Nyuk Hien rallied the NUS faculty staff to help facilitate the parallel workshops. This serves to further strengthen our enduring partnership with NUS, which spans over many years in addressing the challenges and developing solutions for our built environment.

Credit is due to the taskforce that was assembled in quick time to see to the registration of delegates, transportation arrangements, coordination of the site visit to UWCSEA Dover Campus, catering for the tea breaks and lunch, and the networking dinner at the National University of Singapore Society Guild House at Suntec City.
Last, but not least, the success of this FBF Workshop would not have been possible without the presence of our IEA delegates and the local community who have contributed to the lively discussions and exchange of ideas. It is hoped that this document will provide valuable inputs to the development of the strategic plans for the various TCPs for the next five years and we look forward to implementable solutions to transform cities in hot and humid climates towards more efficient and sustainable energy use.

Noel Chin
Coordinator for the IEA Future Buildings Forum Think Tank Workshop 2017

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Executive Summary

The theme for the sixth International Energy Agency (IEA) Future Buildings Forum (FBF) Think Tank Workshop focused on "Transforming cities in hot and humid climates towards more efficient and sustainable energy use". As shared by Mr Keisukei Sadamori, the projected energy demand is anticipated to increase as a result of the growth in construction, especially in the Asia-Pacific region which would account for nearly half the expected global building additions. With air-conditioning becoming a necessity in the tropics, energy demand is expected to grow at a rate of more than 10% per year. There is therefore an urgent need to rethink about the approach towards passive design, thermal comfort and the need for disruptive technologies for the tropics as a response to the increasing need for cooling.

This two-day FBF Workshop, held in Singapore from 24 - 25 October 2017, set out to discuss the various challenges, opportunities and R&D priorities that would inform the development of the respective IEA buildings-related Technology Collaboration Programmes' (TCPs) strategic plans for the next 5 years. It was attended by 34 delegates from the various IEA TCPs, together with researchers, industry and government agencies from the Singapore community.

Prof Lam Khee Poh delivered the keynote speech that emphasised the need for adaptability and explained how the National University of Singapore overcame the challenges of the need for cooling with innovative designs and use of technologies to achieve net-zero energy status for their forthcoming School of Design and Environment (SDE4) building. Other renowned experts spoke about various considerations needed to tackle the energy demands of hot and humid climates. These range from the basic need to embrace passive design like insulating building envelopes and use of ventilative cooling strategies, the various forms of energy efficient technologies such as heat pumps, LED lighting, and thermal storage, through to district energy solutions coupled with renewable energy sources such as solar PV and solar thermal cooling to power absorption chillers to offset energy demand. Case studies were also shared about achieving zero carbon in a township in Vietnam and Singapore's aspirations for positive / zero / super-low energy buildings in the tropics. To make these possible, proper planning and policies must be developed to encourage the rate of adoption to meet global reduction in energy use, such as those proposed by the Building Energy Efficiency Accelerator, the IEA Energy Technology Perspectives 2017's 2°C Scenario (2DS) and the Beyond 2°C Scenario (B2DS) under possible future climate change, as well as by the Mission Innovation Challenges. Not forgetting the occupant needs, technologies should focus on achieving comfort, health and well-being (or adaptive thermal comfort) in buildings, communities and cities. The presentations provided participants with a background of the current challenges and state of the art technologies, and helped to stimulate the thought process to create engaging discussions.

Challenges and Opportunities

Many challenges to implementation surfaced from the parallel discussions, such as the absence of information (right price signals to drive decisions that minimise societal costs), and the need for government intervention (mandatory adoption of technologies at a district or community level), which may not materialise if left to market forces.

Frameworks for funding initiatives and implementation guidelines would help see through early adoption especially in developing nations. While there was no shortage of technologies in the discussions, it was agreed there is a need to understand the context (environmental challenges and occupant needs), and the applications of the right strategies and technologies to achieve the goals of reducing energy demand.

However, opportunities presented where leadership from both government and industry can play a major role in rolling out policies, standards and guidelines, financial frameworks and development of deployment roadmaps.

Relevant Challenges and Opportunities to be addressed are:

1. **Multiple benefits**: evidence of benefits (health, well-being, thermal comfort, acoustic comfort, economic, convenience)
2. **Construction quality**: training, guidelines and commissioning
3. **Government policies** created through evidence-based analysis that enable investments (e.g. green estate investment fund, green bonds, subsidies).
4. **Standards and regulations** as a very effective means for affecting the design and operation of buildings.
5. **Investment**: walk the talk and readiness for finance
6. **Market transformation**: bulk purchase for economies of scale, versatile, standardized products and supply chain engagement
7. **Evaluation**: evidence based decision making accounting for the lifecycle of the building
8. **Low embodied energy and embodied greenhouse gas emissions** for building materials, technologies and equipment
9. **Planning**: guidelines for appropriate design and planning, accounting for full cost of energy, including externalities over the building lifecycle

R&D Priorities

Most important are the R&D priorities that emerged from the FBF Workshop to address the challenges, and which lay out the scope for the various TCPs to adopt in their strategic plans for the next five years. These priorities are summarised below:

Building HVAC and systems:

1. Research **dehumidification** solutions based on sorbents and the use of solar thermal for regeneration of the materials.
2. Develop **building sensors, controls, automation** with AI and predictive algorithms to increase control and responsiveness of the building.
3. **Optimize use of limited space in high density and high cost real estate** by use of compact thermal energy storage for low exergy systems.
4. **Improve design guidelines and standards** for building and system design, including for passive and active systems, such as radiant cooling, natural convective cooling, natural ventilation.
5. **Improve building and design in practice,** including for hybrid systems, heat and waste heat recovery, and occupant-centric buildings to improve overall system efficiencies.
6. **Water saving strategies for condenser cooling** such as technical and regulatory strategy for using TSE (treated sewage effluent) in cooling towers, potential use of grey water.
7. Investigate lifetime and performance of **renewable energy systems coupled with batteries** in hot and humid climates, and study battery materials that are stable in hot and humid environments that are abundant in the earth's crust.
8. Address **data centres,** which are significant electricity consumers, through improved cooling techniques, heat recovery and using low grade heat and low temperature differences that enable higher performance.

Building envelope and occupant behaviour:

9. **Integrate passive design with active façades**, including with PV, solar thermal systems and smart controls to improve both the building envelope and energy generation.
10. **Construction quality:** Need in building the capability of scientist and building experts through collaborative, cross climate research projects, internships, and trainings to adopt best practices for sustainable building envelope design.
11. Conduct socio-economic R&D to better **understand occupant behaviour** in view of shading controls, and for alleviating the load on the grid.

City and District scale:

12. **Capacity building** is essential for research, modelling, bioclimatic buildings and for holistic and integrated urban planning.
13. Develop guidance for **planning and design of integrated infrastructure** by means of user-friendly flexible analysis models.
14. **Demonstrate state of the art of district cooling and integrated infrastructure.** Analyse collected data to validate and refine analysis models and tools and to provide evidence for policy makers.
15. **Peer-to-peer renewable electricity transactions for AC using blockchain**: design and execution of such a system in small communities. Encourage new business models to be designed that may improve market efficiency.

Grid and storage interaction, renewable integration:

16. **Green corridors**: investigate the development of dedicated transmission lines to transport renewable energy generation from regions of high renewable resources to regions with low renewable resources but high load demands.
17. Study **big data** obtained from energy meters to understand the city / state / country's load demand for better manage the integration of renewable energy.

In general, it was concluded the level of R&D that focuses on solutions for tropical and sub-tropical regions needs to be increased. Additional sub-topics can be found in the more detailed list given in Appendix 5.

1. INTRODUCTION

The IEA Future Buildings Forum (FBF) Think Tank Workshops are convened every five years to agree on strategic R&D priorities for the IEA buildings-related Technology Collaboration Programmes (TCPs). The ultimate purpose of the FBF is to identify appropriate solutions for buildings and community energy systems to meet the challenging goals of clean energy supply and energy demand reduction. To help to achieve this, there is a need to identify future R&D to optimise interactions of individual building and building clusters with smart energy grids, future R&D to develop promising technologies at the pre-commercialisation stage, and opportunities emerging from the outcome of future R&D for large-scale deployment.

The previous FBF Think Tank Workshop held in 2013 in Soesterberg, the Netherlands, was centred around the theme "Transforming the Built Environment by 2035: Meeting Energy and Environmental Targets". While many R&D priorities were identified under the three broad areas of energy reduction, energy storage and management, and energy production, other non-technical challenges were surfaced such as financial, legal and human behaviour that need to be addressed to reach the 2035 goal for transforming the built environment.

The theme for this latest FBF Think Tank Workshop 2017 was climate specific, focusing on "Transforming cities in hot and humid climates towards more efficient and sustainable energy use". Due to increasing need for cooling, dehumidification and ventilation in the tropics, there is a need to consider other ways to reduce the energy intensity to maintain thermal comfort and manage energy systems. This would include the deployment of low carbon solutions for buildings and the communities.

The FBF 2017 was organised by IEA EBC, BCA and NUS, and was held in Singapore at the BCA Academy from 24 - 25 October 2017. The occasion was graced by Mr Keisuke Sadamori, Director of Energy Markets and Security, IEA. A list of renowned international experts from the various TCPs shared at the plenary to give a flavour to the challenges and state of the art technologies to help stimulate and energise the parallel discussions. The parallel discussions were organised into the following themes:

Challenges:
- Policy Making and Implementation
- Technology Meets Market Demand
- Technology Implementation

Opportunities:
- City and District level: technology needs and solutions/policy and market implementation
- Building level: technology needs and solutions
- Building level: policy and market implementation

R&D priorities:
- Building HVAC and systems
- Building envelope and occupant behaviour
- City and District scale
- Grid and storage interaction, renewable integration

There was a good mix of participants in the parallel discussions from different segments of the built environment value chain, ranging from government and the private sector, industry, innovators, decision-makers, community energy planners, regulators and academia. A total of 34 delegates from the IEA buildings-related TCPs and 70 from the Singapore research community and industry attended the FBF and provided an excellent opportunity for exchange of ideas and knowledge during these sessions.

We are very confident the discussions have paved the way forward in identifying the R&D needs to address the theme and hope to see these R&D work translate into commercial solutions to be deployed in the tropics in the near future.

2. WELCOME AND OPENING

2.1 BCA Welcome Speech

Tan Tian Chong, Deputy Managing Director, Built Environment Research and Innovation Institute, Building and Construction Authority

"Mr Keisuke Sadamori, Director of Energy Markets and Security, IEA, Mr Andreas Eckmanns Chair of IEA EBC, Distinguished guests, welcome to the BCA Academy and the IEA Future Buildings Forum."

"This is a very important forum which is organized once in 5 years by the IEA research community. It is the time to take stock of the research efforts in the various R&D groups and assess the needs in the coming years. The goal is to establish the priorities and directions for the TCP programmes in the next few years."

"The theme for this forum is "Transforming Cities in Hot and Humid Climates Towards More Efficient and Sustainable Energy Use." I think you will agree that Singapore is a very appropriate city to host this forum. For those of you from the temperate zones especially, you will have first-hand experience of the 33°C - 34°C heat, the high relative humidity, together with the thundery showers in the afternoons."

"The Forum's theme actually resonates very well with Singapore's desire and ambition to play a useful role in advancing green building research and innovation in the tropics. We are therefore very heartened to be able to host this event jointly with the National University of Singapore (NUS) and IEA EBC with help from the TCPs."

"Over the next two days, we will focus on two key challenges in our discussions. First is the increasing needs for cooling, dehumidification and ventilation. Second, the development of low carbon buildings and communities. To meet these challenges, disruptive advancements will have to be made to the design, construction and operations of buildings and communities. For instance, we may have to "re-invent" the air-cooling system to suit the hot humid tropical climate. Smart systems with artificial intelligence (AI) capabilities may have to be an integral part of the building system to ensure their optimal performance."

"And these disruptive changes will not be just technological. Mind-set and behavioural changes may also be necessary, even critical. We may have to re-think our ideas of passive design. Should we re-define thermal comfort? Should we take a more adaptive approach and define thermal comfort in the context of the tropical climate, the activities we are engaged in and the type of building or facility? I will not spoil your fun by going into the details as you will be spending a lot of time on such discussions in the next two days."

"To ensure our forum participants are thoroughly engaged, we have lined up a host of distinguished speakers. They will contribute to the Challenge Statement session and the State-of-the-Art briefings. I am sure they will provide interesting and useful background information and expert perspectives that will stimulate the Think Tank workshop deliberations."

"I would like to thank all these distinguished speakers and also the NUS team who will be facilitating the workshops. Finally, I would also like to thank all participants and wish all of you a fruitful and rewarding programme ahead."

2.2 IEA Welcome Address

Keisuke Sadamori, Director Energy and Security, International Energy Agency

"Good morning ladies and gentlemen. It is a great pleasure to be here today to open the Future Buildings Forum. I have just attended the 10th anniversary meeting of the Singapore International Energy Week, and I think it is fitting that the Future Buildings Forum should be back-to-back with this important energy event. Indeed, buildings will play a strong role in shaping our energy future."

"The global buildings sector is growing at unprecedented rates and we only need look around us here in Asia to see that it is happening almost overnight. Indeed, every time I come back to Singapore, to Beijing, to Delhi, to Jakarta ... the skyline is never the same."

"And it will keep changing. Over the next 40 years, the IEA estimates that the world will build more than 280 billion m2 in new construction. That growth equals more than 10 thousand m2 per minute, meaning we will build the equivalent of Paris every week over the next 40 years. Growth will be especially strong here in Asia Pacific, which accounts for nearly half of expected global building additions. Put in comparison, this region will add the equivalent of both Petronas Towers every hour over the next 40 years."

"Energy demand in buildings is also changing. 20 years ago, air conditioning was considered a luxury in most countries. Last year, about four air conditioners were sold every single second. In rapidly emerging economies, like India, Indonesia, Vietnam and the Philippines, energy demand for air conditioning is growing at more than 10% per year."

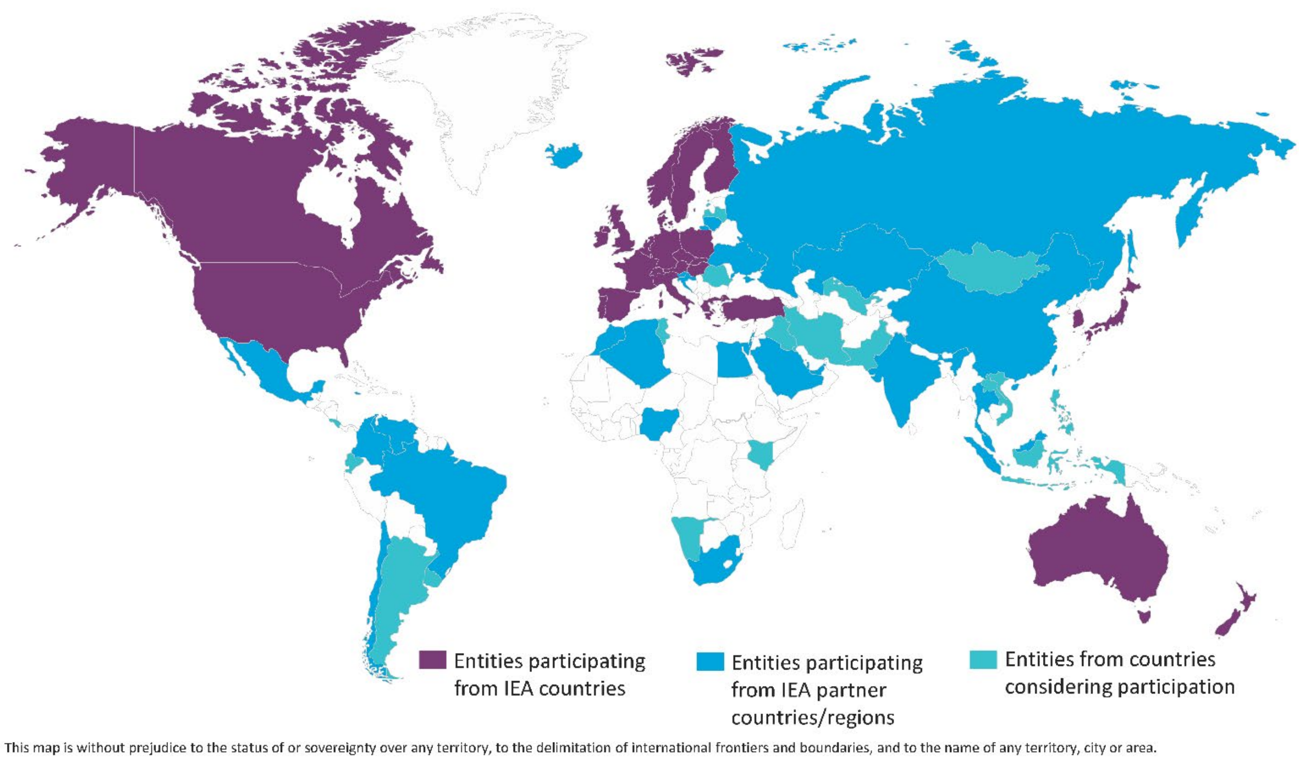
"It goes without saying that the buildings sector will play a key role in shaping the future of the energy sector, which is why this future buildings forum is so important. Buildings can last a very long time 30, 50 or up to 100 years, so what we do today will impact what we can do tomorrow."

"I am very glad to be here today with our many colleagues from the IEA Technology Collaboration Programmes. These international cooperation platforms of 6,000 experts from more than 50 countries, including many countries here in Asia and they are helping to innovate and change the world.

"I do not need to tell you that there are many challenges in buildings, ranging from energy access and affordability, health, and safety, to name a few. We should not forget that at the heart of buildings are people and their different needs. So I'm glad to see that the heart of this forum is trying to meet those needs through energy efficient and sustainable solutions, especially for the world's most rapidly growing regions in hot and humid climates."

"I want to thank the colleagues here at BCA, the IEA Energy Buildings and Communities TCP, and also all the IEA TCPs here today for bringing together this important forum. I also want to thank Singapore, who joined the IEA as an Association country last year at the Singapore International Energy Week, for graciously hosting the forum."

"We are also very grateful to Singapore, who hosted our first ever and very successful, energy efficiency training week for Asia Pacific in July this year. Like the future buildings forum, the IEA's Energy Efficiency Training Weeks are an important event that will bring together more than 600 policy makers this year alone to help identify the policies and solutions that will set the world on a more efficient and sustainable pathway. Thank you, and I wish you all a successful conference."



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2.3 Future Buildings Forum Opening

Andreas Eckmanns, Chair, IEA Energy in Buildings and Communities Programme

In his opening address Andreas Eckmanns introduced the IEA that was founded in response to the 1973/74 oil crisis within the framework of the Organisation for Economic Cooperation and Development (OECD) with its initial role to secure oil supply through the release of emergency oil stocks. Today, the IEA works to ensure reliable, affordable and clean energy for its 28 member countries and beyond with energy security, economic development, environmental awareness, and engagement worldwide as their main areas of focus. The IEA's TCPs enable collaborative R&D projects among their member countries. Out of a total of 39 TCPs, 9 are buildings-related: EBC, ECES, 4E, DHC, DSM, HPT, ISGAN, PVPS, and SHC.

In June 1991, the Future Buildings Forum (FBF) was officially established under the IEA "Energy in Building and Communities" (EBC) Programme. Being a regular activity jointly run with other related IEA TCPs every five years it is intended to identify long term energy, environmental, economic and other technical and non-technical issues, and to assess their potential effects on future building energy demand, supply and operation. It aims at involving a broad spectrum of experts from science, funding agencies and industry.

Under the title "Transforming Cities in Hot and Humid Climates Towards More Efficient and Sustainable Energy Use", the 6th FBF Workshop convened in Singapore addresses the challenges of meeting increasing needs for cooling, dehumidification and ventilation, and deploying low carbon solutions buildings and communities. The objectives of this Workshop are to identify:

- future R&D needs over the next five years,
- future R&D needed to optimize interactions of individual building and building clusters with smart energy grids,
- future R&D required to develop promising technologies (pre-commercialisation), and
- opportunities emerging from outcome of future R&D (large scale deployment).

The FBF 2017 brought together about 100 workshop attendees from 20+ countries, mainly experts from academia, industry, research institutes, government, funding agencies, planners and consultants. Andreas Eckmanns expressed his thanks to BCA and NUS for hosting and facilitating this two-day event and wished everyone an inspiring FBF workshop.

3. FINDINGS

In this section, the findings resulting from the FBF Think Tank Workshop 2017 are concluded. A detailed collection of topics as reported from each group in the parallel discussions can be found in Chapter 5.

3.1 Challenges

The first parallel discussion focused on the challenges, looking at barriers and obstacles for policy, market and technology implementation.

Energy tariffs do not include the full cost of energy including externalities. This approach is a disadvantage to both energy efficiency and renewable energy project financing.

Energy supply and grid planning is often disconnected with the building sector and clean energy sector planning. The inclusion of energy storage in buildings or renewable energy systems can be cost-prohibitive when paid by a project developer, but may be more easily financially justifiable for a utility or government.

Lack of evidence and understanding of the energy and non-energy benefits for stakeholders is of concern. Project developers, policy makers and financial institutions would make improved decision making with improved data and evidence.

Lack of understanding of technologies and increasing complexity of technologies affects purchasing decisions, installation, operations and maintenance. Complex systems with customized parts possess challenge to adaptability, can increase training and installation cost, and result in the need for more frequent upgrade or replacement.

Figure 2: BCA Skylab
Source: Andreas Eckmanns

Lack of proper installation and commissioning can reduce market confidence in the quality of the technology. No matter how good the technology is, it will fail if installed the wrong way.

Lack of resilient and simple technologies can limit the effectiveness of technologies in extreme. Adaptable technologies impedes adjusting for changing occupant and building needs.

Lack of standardized components within technologies increases the cost for maintenance, replacement parts and training.

Split incentives continue to be an issue when the owner pays the capital cost and the renter pays the operational costs.

Lack of policies to fund R&D reduces the willingness for organizations to take financial risk and limits the likelihood that funding is available for the right projects.

Higher cost of advanced technologies can limit the market adoption, as products must be affordable for consumers to implement.

Balancing thermal comfort with performance (indoor air quality, noise, daylight, etc.).

Meeting the needs of the occupants and influencing occupant behaviour across different occupant types (cultures, location, economic, etc).

Lack of product testing in some markets results in reduced product quality and consumer confidence in new technologies.

3.2 Opportunities

The second parallel discussion focused on the opportunities, with the aim to identify the means to address the existing challenges in the fields of technology, policy and market implementation.

Government policies created through evidence-based analysis (more comprehensive coverage of both benefits and costs). Creating policies that enable investments (e.g. green estate investment fund, green bonds, subsidies). IEA and IEA-TCPs could consider hosting or coordinating efforts for low carbon communities (cities) in the tropics and continue to engage with governments to support policy-making.

Technology Roadmaps can be used as frameworks to drive solutions and for promotion of technologies availability.

Local political leadership is a powerful factor in development of practices and systems for sustainable cities. Education of political leaders and policymakers can help them to see what is possible, understand the opportunities, challenges and benefits of sustainable energy systems, and learn how to evaluate, plan and implement sustainable practices and systems.

Local leaders can also help their communities shift the mindset regarding energy from "energy supply and demand" to focusing on the services that result from energy use, i.e. **thermal comfort as a service.** This can facilitate creative ways to meet the real needs of the community more sustainably.

Cities to take more leadership, in promoting exemplary solutions, bulk procurement (e.g. bulk purchasing of energy efficient products), and **outcome-based regulations,** e.g. performance based incentives (provides measured data for policy making as a co-benefit)

Cities can play a crucial role by developing the **city-wide planning and policy framework for sustainability.** Such a framework must be far-sighted and may include standards and regulations, zoning, assessment of cooling opportunities, and integration of infrastructure systems (see below for details).

Standards and regulations are a very effective means for affecting the design and operation of buildings.

Zoning affecting the mix of building spaces within districts, as well as the potential access to low carbon waste heat or renewable energy sources.

Assessment of cooling opportunities for district cooling based on thermal load density and local opportunities for low-carbon cooling sources.

Integration of infrastructure systems to create synergies, e.g. reducing carbon emissions by using output from one system to supply another system, or reducing costs by installing all street utilities at the same time.

Marketplace Stakeholders engagement (i.e. banks). Enabling banks to understand the evidence. Form relationships first and then implement change later by selling services.

Planning on a district level, within the city-wide sustainability framework, can take place based on the timing and pace of new development or retrofits. Mixed use districts can enhance sustainability in multiple ways, i.e. reducing transportation requirements, improving load diversity to reduce peak demand, and facilitating beneficial use of waste heat.

District systems should be implemented in districts where such systems provide strong sustainability benefits cost-effectively. District system development generally takes place based on uptake of customers through long term contracts, but the business model of the implementing entity may take many forms, e.g. city-owned, private non-profit, private for-profit, public-private partnership, etc.

Storage as an intermediary between the renewable plant and the grid, it could absorb excess renewable energy generated that could otherwise introduce grid instability. Storage could also enable fast response to variable customer loads, thereby reducing the strain on the grid.

Human behaviour has a strong impact on use of energy, water and other resources, and it is important to communicate with and provide information to consumers during the planning process (i.e. refurbishing of districts, discussions on improvements), as well as during ongoing use of utility systems.

Consider the different climates and seasons prevalent in the country and avoid inappropriate technology / design habits transferred from other climates. More data are needed for tropical climates e.g. daylight designs appropriate to the tropical climate.

Consider passive design (non-AC buildings), especially in countries where people cannot afford air conditioning (half of the world's population).

Integrate **smart control** into building systems, so that buildings are responsive and adaptive to both internal and external factors / situations.

Need to take note of complacency from designers and providing **training** to improve technology awareness and increase competency of designers.

Building façades should be designed beyond thermal insulation e.g. dynamic façade, shading and day-lighting.

Instead of HVAC, use low energy **dehumidification** technologies for removal of moisture compared to lowering temperature.

Hybrid ventilation and cooling by switching off the AC whenever passive cooling or natural ventilation solutions are adequate to ensure that the temperature falls below the required set point (different technology for inverted and non-inverted ACs).

Usage of **building materials with low embodied energy and greenhouse gas emissions** other than conventional building concrete, with awareness that low tech systems may have lower embodied energy and greenhouse gas emissions than innovative systems.

Engage occupants to reduce wastage of energy.

Figure 3: BCA Academy Campus with Zero Energy Building (right side)
Source: Andreas Eckmanns

3.3 R&D priorities

The third parallel session focused on R&D priorities for addressing the challenges.

Building HVAC and systems:

Increase the level of R&D that focuses on **solutions for tropical and sub-tropical regions.**

Research **dehumidification** solutions based on sorbents and the use of solar thermal for regeneration of the materials.

Develop **building sensors, controls, automation** with AI and predictive algorithms to increase control and responsiveness of the building to weather, occupancy, occupant needs, energy prices, energy quality, etc. This includes enabling sensor and control technology that are cost effective, such that currently many sensors are either too accurate or not accurate enough.

Optimize use of limited space in high density and high cost real estate by use of compact thermal energy storage including novel PCM materials which operate at higher temperature level about 17°C-19°C for low exergy systems.

Improve **design guidelines and standards** for building and system design, including for passive and active systems, such as **radiant cooling, natural convective cooling, natural ventilation** with improved thermal comfort and improved air quality (decreased transfer of pollutants, irritants and pathogens).

Improve building and design in practice, including through the design of **hybrid systems, heat and waste heat recovery, and occupant-centric buildings** to improve overall system efficiencies.

Water saving strategies for condenser cooling such as technical and regulatory strategy for using TSE (treated sewage effluent) in cooling towers, potential use of grey water.

Investigate **lifetime and performance of renewable energy systems coupled with batteries** in hot and humid climates, and how the ambient temperature of the battery affects the lifetime and performance of the coupled system. Furthermore, battery materials that are stable in hot and humid environments that are abundant in the earth's crust should be studied.

Address **data centres**, which are significant electricity consumers, through improved cooling techniques (chip cooling, displacement, heat pump, chillers), heat recovery (heat pumps / exchangers) and using low grade heat and low temperature differences that enable higher performance.

Building envelope and occupant behaviour:

Integrate passive design with active façades, including with PV / solar thermal systems and smart controls to improve both the building envelope (including daylight / glare control, heat rejection, and thermal comfort) and energy generation.

Construction quality: Need in building the capability of scientist and building experts through collaborative, cross climate research projects, internships, and trainings to adopt best practices for sustainable building envelope design.

Understand occupant behaviour in view of a) individual control of shading devices by occupants versus automated, smart and predictive controls, and b) for alleviating the load on the grid. For a better understanding of occupant behaviour in tropical climates, socio-economic R&D should be conducted.

City and District scale:

Capacity building is essential for research, modelling, bioclimatic buildings and for holistic / integrated urban planning (incorporating energy, water, land and food).

Develop **guidance for planning and design of integrated infrastructure** (cooling, electricity, natural gas, waste water treatment, potable water, mobility) by means of user-friendly flexible analysis models.

Demonstrate state of the art of district cooling and integrated infrastructure. Analyze collected data to validate and refine analysis models and tools and to provide evidence for policy makers.

Peer-to-peer renewable electricity transactions for AC using blockchain: With the advent of blockchain technology as a transparent database with low transaction costs, the technology has the potential for peer-to-peer electricity trading at affordable prices for powering consumers AC and other appliances. The design and execution of such a system in small communities could be looked at, along with the uptake and consumer response. This would encourage new business models to be designed that may improve market efficiency.

Grid and storage interaction, renewable integration:

Green corridors: In countries organised into several states, the development of dedicated transmission lines could be investigated to transport renewable energy generation from regions of high renewable resources to regions with low renewable resources but high load demands.

Study **big data** obtained from energy (generation and consumption) meters: Data obtained from electricity retailers would be beneficial to understand the city / state / country's load demand. With the load demand understood, the integration of renewable energy, and its intermittent nature, could be managed better.

4. PRESENTATIONS

The presentations held at the FBF 2017 included two keynote speeches to set the scene, six challenge statements that served as an opener for the parallel discussions, and nine technology briefings to bring all participants to the same level of knowledge. While the speeches are summarized below, the presentations are available online at www.iea-ebc.org/strategy/future-buildings-forum.

4.1 Scientific Keynote

Lam Khee Poh, Dean, School of Design and Environment, National University of Singapore

Prof Lam's presentation centred on the need for adaptability as a means to survival. Various building types were cited like the Eskimo Ice House, Egyptian Residence and the Cave Houses in Shaanxi and how "comfort" was achieved through the use of correct insulation and thermal mass respectively. In the tropics, The Taman Tropika House leveraged on the cultural aspects in its design to achieve comfort. He went on to explain how exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir. When the surroundings are the reservoir, exergy is the potential of a system to cause a change as it achieves equilibrium with its environment. He critiqued on how various strategies are often expressed in "pretty diagrams" which do not contain sufficient information on how science works and stressed the need for proper modelling (with all assumptions clearly declared) and appropriate simulation tools to help to explain these strategies and its effectiveness in achieving the desired total environmental performance and comfort.

He shared about the challenges Singapore face - being resource and alternative energy disadvantaged, heavily constrained by the type of fuel sources and hugely dependent on the import of energy to meet our needs. This is where the importance of taking a holistic approach to environmental sustainability would help to address our challenges by addressing materials and waste management, encouraging water and energy efficiency to achieve environmental quality and protection. It is important that the NUS "walk the talk" when it comes to striking a balance between achieving energy efficiency and offsetting the energy consumed through the deployment of renewables. This is manifested in the upcoming School of Design and Environment (SDE4) project, which is slated to be the first purpose-built 5-story net-zero energy building in the Singapore. As part of the detailed design considerations, there were many daylight and thermal measurements undertaken in mock-up test rooms, and surveys were conducted to develop and test a hybrid conditioning system to address the human comfort levels. He also stressed the importance of "green buildings" as it helps to reduce health related issues at the workplace and we need to constantly find ways to improve indoor environmental quality in buildings.

4.2 Industry Keynote

Lee Eng Lock, Deputy Chairman and Senior Technical Director, Measurement and Verification PTE Ltd

Mr Lee shared candidly about the various building projects in which he has been involved. These retrofit projects were able to achieve very good payback of 2-3 years just by addressing the "pain-points" versus replacing the entire chiller plant. He elaborated that good design is fundamental to ensure that the system is able to perform at its optimum capacity. This would include the removal of unnecessary bends and reducing the pressure drop in the piping design and the correct design of cooling tower layout to achieve optimum heat rejection. However, he cautioned that retrofits are just the beginning of the life-cycle and the need for continuous monitoring is of prime importance. This can be achieved through the use of sensors and instrumentation calibrated for accuracy according to the standards and codes. The useful data will help to identify where the inefficiencies are so that facility managers will be able to address them.

4.3 IEA Energy Technology Perspectives

Brian Dean, Energy Efficiency Division, IEA

delivered a presentation on the global perspectives of how building technologies can impact future energy use and emissions in the buildings sector. The building sector is currently not on track to meet global targets as energy efficiency in buildings has historically (1990-2016) not kept pace with the growth of energy use caused by population and economic gains. However, with the 2°C Scenario (2DS) and the Beyond 2°C Scenario (B2DS), building technologies and policies can lead to both energy and emissions savings to reverse historical trends. Major shifts identified in these scenarios include increased electrification, increased use of renewable energy and significant energy savings in heating and cooling (Mission Innovation challenge #7). From a technology perspective, the efficiencies of heat pumps and LED lighting are expected to continue to improve through RD&D. While space cooling is currently the fastest growing building end-use, with deployment of best available cooling equipment the energy consumption for space cooling globally could decrease while achieving increased thermal comfort for people in buildings. The building envelope is key to the lock-in effect of delaying action on energy efficiency, and therefore energy renovations and net zero energy building (nZEB) new construction are key to improving the global building envelope stock. The call to action for the buildings sector includes shifting global investments from inefficient to efficient buildings to deliver "Energy Efficient Prosperity" through the multiple benefits of energy efficiency. The IEA TCPs are key to deliver on the recommendations for improved technologies and policies with efficient building envelopes, heat pumps, appliances, controls, lighting, thermal storage, district energy solutions and solar technologies.

4.4 Industry and Business' View on Solar Thermal Cooling

Christian Holter, SOLID

delivered a presentation on Solar Thermal Cooling which has proven its technical viability and reliability in several projects since 2002 in commercial scale. The economic benefits justifying investments are attractive in large project with capacities exceeding 200 tons of load or in combinations with hot water, waste heat or other integrations into the buildings heating and cooling system. Recent projects of the last five years show a sharp learning curve with significant improved collectors as well as reduced operational energy needed for pumps and vans. The best systems today perform on a daily COP of up to 35 kWch/kWel. However, systems should be optimised to save as much as possible in many operation hours as well in part load with lower COPs. Currently, systems are predominating in tropical and hot environments, but under specific combinations, actual projects in temperate zones can have attractive ROIs too. Due to climate change, new designed buildings should consider future increase of more cooling demand already today with the right measures.

4.5 Future Challenges of Cities: Sustainable, Resilient and Low Carbon

Deo Prasad, FTSE

delivered a presentation on Future Challenges: Sustainable, Resilient and Low Carbon Cities. Rapid urbanisation is a mega trend globally and it is anticipated that cities will host two thirds of the world population by 2050. In Asia Pacific, it's not only the mega cities (population in excess of 10m) but the number of smaller cities which will host larger numbers of people. So the challenges that lie ahead in terms of provision of infrastructure, services, amenity for all ages and their well-being while ensuring economic competitiveness and environmental sustainability need significant attention. As we move from the exploitive approaches (wealth associated with increasing ecological footprints) towards more resilient approaches that foster sustainable and even regenerative approaches are needed. How we plan and design future cities will need to consider approaches to decentralised renewable energy, better water, waste and air quality management, prepare for major disruptions in transport modes and technologies, urban microclimates, and high performing buildings with high levels of intelligence that links buildings, energy grids and transport systems. A key factor in all this is the comfort, health and well-being of residents – in buildings, communities and cities.

This calls for more participatory approaches in decision making on design, planning and policy. Technologies alone cannot solve future problems, so people have to be engaged in better solving problems and creating cities that meet the challenges mentioned.

4.6 Zero Energy Townships in Vietnam

Poul Erik Kristensen, IEN Consultants

shared on the project he was working on with the Nam Cuong group which is a leading property developer in Vietnam, and their wish to develop a large community outside Hanoi towards Zero Carbon status. The presentation outlined a vision for how this could be achieved, based on 50% energy savings in buildings, 25% covered by solar PV on the buildings, and the remainder 25% energy consumption sourced from the grid during off peak periods, noting that 25% of electricity in Vietnam is produced from hydropower. This new community is not planned to contribute to an increase in electrical peak load, therefore instead of investing in new power capacity, Electricity of Vietnam (EVN) should invest in energy efficiency and renewable energy corresponding to the savings in peak power investments. The presentation documented that investing in energy efficiency in buildings is cheaper that investing in new power capacity, hence seen from a macro-economic view, this will be the preferred option: Negawatts instead of Megawatts.

4.7 Singapore's Positive / Zero / Super-Low Energy Buildings Challenge for the Tropics

Gao Chun Ping, BCA

presented on Singapore's aspiration of Positive Energy Low-rise, Zero Energy Mid-rise, and Super Low Energy High-rise Buildings in the Tropics. To achieve 60-80% improvement of building energy efficiency from 2005 levels by 2030, BCA is working with the industry to drive research and innovation to address the challenges of the dense urban environment and tropical climate. While solar PV has been identified as the only viable solution of renewables, the limited space in the city state restricts the supply side and requires pushing the boundary of energy efficiency. BCA is currently developing a Technology Roadmap that identifies key R&D areas and emerging technologies suitable for the tropics. With the detailed implementation plans being formulated, this roadmap will chart the pathway of technology development and accelerate the demonstration and deployment of net zero energy buildings in Singapore.

4.8 The Building Energy Accelerator and its Work with Cities

Sumedha Malaviya, World Resources Institute India

shared on the Building Energy Efficiency Accelerator (BEA) which was launched in 2015 at the Paris summit. BEA assists sub-national governments in speeding up the process of adoption of best-practice policies and implementation of building efficiency projects, with the goal of doubling the rate of energy efficiency improvement in the building sector by 2030.

The BEA global partnership is designed to complement existing networks of cities with a venue for engagement with private sector partners. The BEA process of engagement in a city includes support for assessing and prioritizing locally-appropriate policies and actions, implementing actions, through matching needs with expertise, resources and tools, and tracking action and documenting progress, and sharing lessons learned.

Cities and subnational governments that join the Accelerator are asked to make three specific commitments to be implemented with assistance from the partnership:

1. Implement one enabling policy
2. Implement one demonstration project
3. Create a baseline of building energy performance, track and report annual progress, and share experiences and best-practices with other governments

At present 28 cities and 70+ organizations, institutions, private sector companies are a part of the accelerator.

Some of the key lessons in phase 1 are:

- Building broad coalitions – shared vision of stakeholders for the local jurisdiction even if political transitions remain difficult;
- Delineating leadership roles – Clear responsibilities, goals, and accountability are crucial for success
- Readiness for finance – cities not ready to talk about finance unless clear about projects and current city contracting or budgeting constraints;
- Achieving scale for finance and impact – Connections with high-level platforms such as SE4all provide an important political link.

4.9 Cooling Technologies

Stephan Renz, Chair, IEA Heat Pumping Technologies (HPT) TCP provided an overview of the recent developments in cooling technologies. Firstly, he started with a glance at the new strategic direction of IEA HPT. As in the past affordable and competitive technologies for heating remain important but more efficient cooling and air-conditioning (AC), especially in warm and humid climates will become a core area. This includes flexible, sustainable and clean system solutions (e.g. in urban areas) using combinations of heat pumping technologies with energy storage, smart grid, solar and wind energy, thermal networks, energy prosumers, etc.

Regarding cooling markets and technologies expectations for the future are rapid growth of AC markets in developing nations with hot and humid climates (Figure 4). This will be accelerated by an increased frequency of extreme heat waves due to global warming. Continued efficiency improvements of cooling technologies are important as well as a transition to Low-Global Warming Potential (GWP) refrigerants. Besides, natural refrigerants and non-vapour-compression AC technologies fulfil this requirement.

The properties of cooling technologies depend on different challenges and opportunities:

- Efficiency of the thermos cycle
- Dehumidification
- GWP of the refrigerant
- Energy transfer from the room
- "Culture" of thermal comfort (temperature, humidity in the room)
- Energy transfer to the environment
- Required temperature lift
- Decentralised or central solution
- Other energy sources / sinks
- Decentralised or central solution
- Other energy sources / sinks
- Need and opportunities of storage system
- Existing building stock or new building
- Size of the building
- Purpose of the building
- Standard of building technologies
- Source of electricity (and its GWP)
- Electricity grid (capacity, total energy demand and peak loads)

Stephan Renz mentioned that besides all technical requirements and issues, the "culture" of thermal comfort is most important. If people insist on a low room temperature independent from the outside temperature, then the energy demand can be very high even with highly efficient cooling systems.

As emerging R&D solutions for cooling technologies he described three areas:

- Advanced Vapour-Compression Systems: AC technologies that significantly lower refrigerant GWP and energy consumption while maintaining cost-

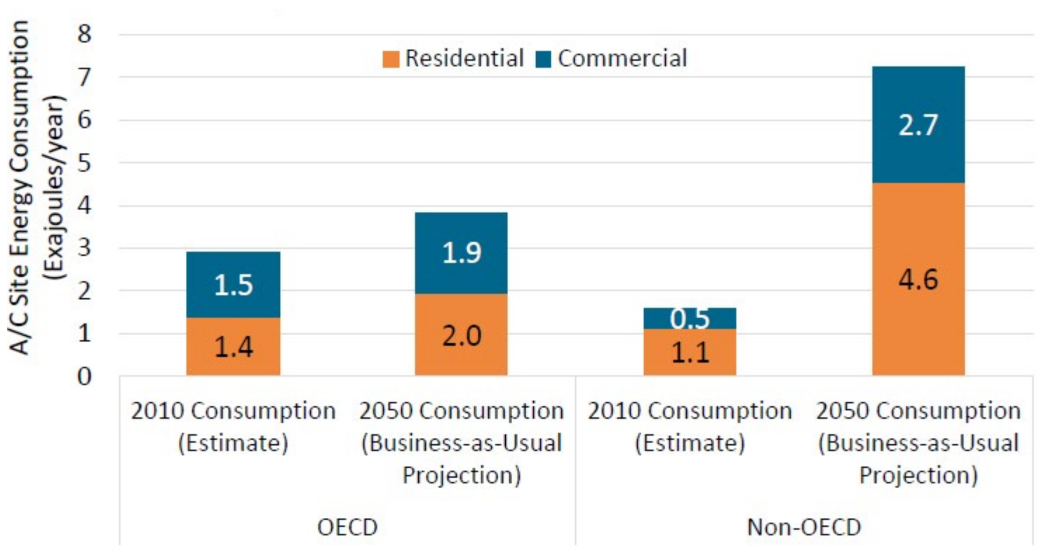

Figure 4: Current and projected space cooling site energy consumption
Source: The Future of Air Conditioning for Buildings, DOE, 2016

competitiveness, for example low-GWP refrigerants (e.g., natural refrigerants and synthetic olefins); climate-specific designs.

- Emerging Non-Vapour-Compression (NVC) Systems: AC technologies that do not rely on refrigerant-based vapour-compression and can provide energy savings (with high-volume cost similar to today's), for example solid-state and caloric (thermoelectric, magnetocaloric); electro-mechanical (evaporative, thermoelastic); thermally driven (absorption)
- Integration of AC and Other Building Systems: AC technologies that share excess heat and other resources with other systems to provide significant savings for the building, e.g. capturing waste energy from AC for water heating and dehumidification

4.10 Solar Cooling

Stephen White, CSIRO

delivered a presentation on Solar cooling which involves direct coupling of renewable energy sources (solar thermal or solar PV) to a thermal or electrically activated cooling machine. This substitutes fossil fuel derived energy sources with renewable energy. It makes intuitive sense, because the availability of the sun broadly matches the demand for cooling in a building. It is a potentially important component in the pathway to zero energy buildings. Furthermore, it can take problematic loads (solar PV generation and air conditioning) off the local electricity grid with important infrastructure benefits.

There are numerous examples of successful commercial installations of solar thermal cooling. While careful design is required, large (MW scale) thermally integrated systems are a financially attractive option. In addition to the ongoing need for system refinement and scale manufacture, new cycle developments that warrant further investigation include:

- Using high performance absorption chillers with high temperature non-tracking solar collectors
- Combined solar PV / thermal systems
- Innovative integration of low cost solar desiccant evaporative cooling with building fresh air management systems

New solar PV driven air conditioning products are starting to enter the market. These systems show high promise for smaller "plug and play" applications. Innovation in this area is driven significantly by power electronics considerations (e.g. AC or DC, battery requirements, etc). Three paradigms of (i) 100% off grid, (ii) 100% solar PV self-consumption with grid import and (iii) full electricity import/export, are possible with different benefits and cost structures. The optimum approach needs to be determined in partnership with the electricity industry who will likely be a key driver of adoption.

4.11 Ventilative Cooling

Nonaka Toshihiro, LIXIL

shared about the activities of IEA EBC Annex 62 "Ventilative Cooling" which started in 2013 and will end in 2018. "Ventilative Cooling" is the application of ventilation flow rates to reduce cooling loads in buildings. The objectives of Annex 62 are to:

1. Analyse, develop and evaluate methods and tools for prediction of cooling need, ventilative cooling performance and risk of overheating in buildings;
2. Develop guidelines for integration of ventilative cooling in energy performance calculation methods and regulations;
3. Extend the boundaries of existing ventilation solutions and their control strategies and to develop recommendations for flexible and reliable ventilative cooling solutions that can create comfortable conditions under a wide range of climatic conditions;
4. Demonstrate the performance of ventilative cooling solutions through analysis and evaluation of well-documented case studies.

Annex 62 deliverables include the State-of-the-art report, which was published in 2015. A design guidebook with examples of utilization of ventilative cooling in various climate areas is being published as a final project outcome. Furthermore, the "venticool" website has been published and venticool conferences have been held for widely spreading the idea of ventilative cooling. The next step for Annex 62 will focus on further development of natural cooling, new developments in effective sun protection, reflective coatings and shadings, and evaporative effects from plants will be considered. In addition, Japanese research related to ventilative cooling was introduced.

4.12 Multi-Scale Energy Systems

Jimeno Fonseca, ETH-FCL

shared an overview of the Multi-Scale Energy Systems (MUSES) project at the Future Cities Laboratory, which aims to develop new methods and tools necessary for the optimisation of future urban energy systems. The vision entails a shift from approaches such as zero energy, low-exergy and integrated design from the building to the district scale. In the near future, we see city districts as the minimum scale of analysis to identify feasible solutions of energy systems in cities. For this, the approach of MUSES consists in a multi-scale view (from building components to building stocks) of how energy systems are configured in cities. This multi-scale approach requires expertise from multiple domains such as process engineering, urban planning and building systems. Through this approach Muses has identified five areas of specialisation. The first is called energy-driven urban design. This area entails the ability to shape the urban form of cities a priori to the design of energy infrastructure. In contrast to current practice, this field could give the opportunity to engineers to optimise the demand of urban areas to suit the performance of energy systems. The second area of specialisation is called agent-based occupancy modelling. This area entails the use of transport-based methodologies and location services as means to better determine the patterns of human mobility in districts. This data could be used as a detailed proxy of energy consumption. The third area is called low-energy district energy systems. This area entails the study of cutting-edge low-carbon technology in buildings at the district scale. The fourth is called agile optimisation. It entails the study of risk of investment on the development of energy infrastructure in Asia. The fifth area is called the City Energy Analyst. The City Energy Analyst or CEA is one of the first open source computational tools for the analysis of urban energy systems. MUSES builds the CEA tool based on the findings of each one of the other areas of expertise. This approach will ease knowledge transfer to future research teams working in this domain.

4.13 Policies for Encouraging Low Carbon Cooling in Hot, Humid Climates

Mark Spurr, IEA District Heating and Cooling (DHC) TCP

gave a presentation on "Policies for Encouraging Low Carbon Cooling in Hot, Humid Climates" where further progress in technology research and development has been made, and should continue to invest in such activities. The technologies to provide low-carbon energy to cities of the future are available but the main barrier is in the policy and market framework for making energy decisions. In most places, it is due to the absence of the right price signals, or policies that correct for an inevitably imperfect market for energy services: tariffs for energy generally do not reflect the full actual costs of energy services, including values for environmental and social externalities as well as full capital, operation and maintenance costs. It is critically important to enable price signals to drive decisions that minimize societal costs. However, it is also vital to mitigate societal impacts through targeted recycling of the additional funds generated through removal of subsidies so that we avoid exacerbating "energy poverty". If full cost-based rates are too politically difficult, then policy-makers should provide capital and / or operating support for low carbon solutions and consider mandating low carbon systems where such systems clearly minimize total societal costs. District cooling systems are critically important for reducing carbon emissions because they facilitate use of low-carbon sources of cooling energy and thermal energy storage, and improve energy efficiency, carbon emissions and cost-effectiveness through optimal equipment loading and expert operation and maintenance. Governments in hot and humid climates are increasingly interested in developing regulations governing district cooling which in some cases would include mandating use of district cooling in high-density areas to help achieve multiple public policy goals, including energy and water efficiency, carbon reduction, cost reduction and enhanced energy supply reliability.

4.14 Energy Storage

Teun Bokhoven, Chair, Energy Conservation and Energy Storage (ECES) TCP

explained the work of ECES on its contribution in the energy transition toward a renewable based energy system by stimulating and facilitating joint RD&D and pre-standardization work. The scope includes applications in heating, cooling and electricity. These can be considered at a centralized level (typical large storage systems) and decentralized, distributed storage systems (i.e. in buildings or industries).

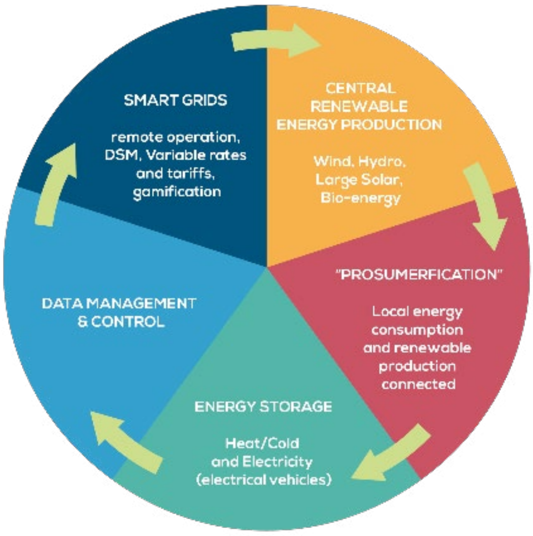

Figure 5: New model of the energy system
Source: TKI Urban Energy

Energy storage is an enabling technology and in most cases, bridges the time lap between (renewable) energy production and demand. Therefore, considering energy storage in a system implies an integral solution. The use of energy storage interacts and will improve the performances of technologies like solar (thermal and PV), heat pumps, smart grids, district heating and cooling, energy conservation, etc.

The current high-priority themes for energy storage in ECES are thermal energy (for cooling and heating), electrical energy, power to "x" options ("x" can be heat, molecules, etc) and modelling storage. For thermal applications, the emphasis is on underground storage and compact storage solutions. For electrical storage, the focus is more on integration storage in (smart) grids, buildings and electric mobility. New electrical storage options are considered like redox flow and storage integration in PV systems.

The emphasis on modelling is required as storage is currently not widely incorporated in the various and commonly used models.

He also elaborated on the transition of our energy system. Our energy system (production, distribution and consumption) is going through a rapid change. From a fossil fuel based (central) energy production we change to a more decentralized (variable) renewable energy production which could be abundant at certain times. At the same time, load profiles are changing through sector coupling (like mobility) and rising comfort levels in many parts of the world. Historically the focus on the technological developments is mainly on production and energy savings for heating, cooling and electricity consumption. New challenges arise by matching variable production and variable load profiles through increased cooling demand and electric mobility. The sector coupling needs a more comprehensive approach (P2C, P2H, P2P, P2M2P, etc.). All these developments require more flexibility within the system and energy storage to bridge the gap between production and demand profiles.

A wide range of decentralized storage cooling options are already commercially on the market such as cold / ice storage for buildings and industries, and district cooling using UTES (Underground storage) / and aquifers for greenhouses and office districts.

The economic evaluation is very sensitive to variations in day / night rates electricity. Further the value of energy storage in general as a solution to avoid investments in energy grids is not widely recognized, and lacks the economic valuation of its deployment. Economic cold storage systems require dynamic pricing and a long-term stability in the overall pricing structure.

4.15 Mission Innovation

Stephen White, CSIRO

presented behalf of Mission Innovation, which is an international initiative (23 countries) seeking to strengthen international clean energy RD&D with the goal of making clean energy widely affordable. Participating countries are taking action to double their public clean energy R&D investment over five years. Seven "Innovation Challenges" have been identified as priority areas for increased funding. One of those is "Affordable Heating and Cooling". This innovation challenge aims to develop new systems and approaches that will reduce the cost of delivering low-carbon heating and cooling of buildings. Six priority areas have been identified inside the innovation challenge as follows:

- Thermal energy storage
- Heat pumps
- Non-atmospheric heat sinks and sources
- Predictive maintenance and optimization
- Building-level integration
- Physiological studies

Survey work has gathered data on existing research activities on these topics amongst the member countries. Perspectives on future research needs in these areas have also been sought. An expert workshop held in Abu Dhabi, UAE, in November 2017, is planned to synthesise this material in order to help identify new areas of research, set targets to track progress and promote international collaboration.

Ultimately, the findings of this work will be published and used to encourage new research and increase pull-through of entrepreneurial innovation in heating and cooling technologies. FBF Workshop participants were encouraged to find their local country representative on Mission Innovation to ensure that the deliberations on future research plans are well informed.

4.16 IPEEC and G20 Updates

Stanford Harrison, Department of the Environment and Energy Australia

shared about the the International Partnership for Energy Efficiency Cooperation (IPEEC) and G20 updates. The IPEEC was formally established in 2009 at the G8 summit in L'Aquila, Italy and resulting from successive meetings of the G8 + 6 economies. IPEEC provides global leadership on energy efficiency by identifying and facilitating government implementation of policies and programs that yield high energy-efficiency gains.

With 17 of the G20 economies as members, it promotes information exchange on best practices and facilitates initiatives to improve energy. There are 10 government led task groups, including the Building Energy Efficiency Taskgroup (BEET). The work of IPEEC is developed by and for government, identifies policy options and levers for government, considers governmental constraints and is non-technical. BEET has published six reports in recent years on building codes, rating systems, metrics and regulatory policies. This work can complement the work of the IEA TCPs.

4.17 Adaptive Thermal Comfort

Yao Meng, Tsinghua University

shared on the work carried out under IEA EBC Annex 69 "Adaptive Thermal Comfort" where reductions in energy consumption and provision of comfortable indoor environment to occupants are both key objectives of the building sector all around the world. The challenge is to find an appropriate balance between these two issues. It is also important to understand the concept of adaptive thermal comfort, which can reflect occupants' real thermal demand.

The concept of adaptive thermal comfort is regarded as a great advance that may play an important role in low energy building design and operation. Annex 69 is helping to bridge the gap between comfort related data and real building applications. Another contribution of Annex 69 is to help international collaboration to establish a universal research framework. To address the specific Annex objectives, the research and development work in the project is separated into three sub-tasks. The activities in each sub-tasks are operated in parallel. Furthermore, one focus of Annex 69 is to deal with the current challenges in adaptive thermal comfort research, and in the spirit that the framework will be universally adopted, the models will be coupled as a whole and efforts will be channelled where most needed.

5. PARALLEL DISCUSSIONS

The first parallel discussion was on the **Challenges** to be addressed, looking at the barriers and obstacles in policy making and implementation, business and market penetration, technology uptake and in addressing occupant behaviour.

The second parallel discussion focused on the **Opportunities,** with the aim to identify the means to address the existing challenges in the fields of technology, policy and market implementation.

The third parallel discussion was on identifying the **R&D Priorities for the next five years.** In-depth discussion was on where and how IEA TCPs contribute to provide solutions, as well as prioritization of each R&D theme.

5.1 Challenges – Policy Making and Implementation

Reported by Rob Kool

The following challenges and solutions were identified during the discussions:

1. Energy prices do not express their actual cost including environmental externalities according to the participants. As such, there are disadvantages to renewables, which limits the energy transition to a lower pace. Subsidies should be rationalized especially for developing countries; pay the actual cost of capacity provided to buildings.
2. Financial framework is a topic to be addressed by policymakers as energy experts and entrepreneurs in the energy field often speak "a different language". As such opportunities are lost. It would be very helpful if policymakers could take the lead in bridging this gap. There are several tools to do this (more data on best practice, guarantees, regulation, etc). At the moment it seems policies are disconnected from energy supply sector and the building sector.
3. Very little information on evidence of energy and non-energy benefits. The multiple benefit studies of the IEA prove there are many more options for financing if these multiple benefits are taken in consideration. The European Union started a Horizon 2020 project on this topic. Evaluation of energy policies in general could be stronger. We all know good examples, but need statistical evidence to prove the points made

Figure 6: Impression from parallel sessions

under (2) and (3). Enable banks to understand the relevant evidence.

4. How to create a need for doing investments for clean energy and low carbon solutions? There are a number of examples (Denmark and California were mentioned) where investments seem much easier than elsewhere in the world. Promote exemplary solutions / lessons learned (e.g. Copenhagen and California) and IEA to host / coordinate low carbon community / cities in the tropics). Develop a roadmap as a framework to drive solutions; Evidence data for policy making. Integrate subsidies into the building codes; create policies that enable investments; bulk purchasing of energy efficient products.
5. Engaging people and making them understand the benefits. Human behaviour does not change so easily. There is increasing knowledge when it comes to energy and behaviour, especially in the Demand Side Management (DSM) TCP. Yet knowledge is not enough, we need investment in behaviour change (both research and programs) to achieve real energy efficiency. The standpoint "if it saves money, they'll do it" has been taken for granted for far too long. Form relationships first and then implement change later by selling services; cross use of knowledge to push forward policies. Take more leadership at city level; IEA to host / coordinate low carbon communities (cities) in the tropics.
6. Split incentives between owner and developer – pay capital cost / operational cost is even after decades an unsolved problem. In line with (2) and (3), financial schemes should be developed to deal with the problem on a national or regional scale instead of case by case solutions. It was suggested to let the marketplace make energy purchasing decisions based on the full cost of energy including externalities.
7. Policies are disconnected from energy supply sector and the building sector, policy makers have to be more aware of the complexity of multiple stakeholders in the process.
8. There is a need for policies to fund R&D; IEA to engage with governments and supporting policies

5.2 Challenges – Technology Meets Market Demand

Reported by Teun Bokhoven

A number of challenges need to be addressed when "Technology meets market demand". The discussion elaborated on the following highlights:

1. Functionalities to match climate, economic, cultural and geographic conditions:

   The geographical location plays a major role in technological solutions to serve specific market demand. Low per capita income countries require low cost technologies and solutions as also government subsidies are difficult to implement. Higher per capita income countries have more opportunities to introduce more technological complex (and therefore more costly) solutions. Geographical factors also plays an important role in technology demand as they add up to other costs like for replacement, transportation, installation and service cost.

   Comparison was made between India and Singapore. For instance -solutions in India generally include measures to avoid hindrance of insects (mainly by installing insect screen on their windows), while solutions in Singapore need to take the typical haze conditions into account. These different conditions and requirement lead to different solutions. From the discussion is was suggested that, in this example, more can be done to incorporate features that can deter insects into existing technologies e.g. filters set on in-blowing ventilators.Another functional requirement was mentioned whereby the effects of air pollution can be solved by implementing new sensor technologies and innovative filters.

   Another challenge mentioned referred to the need to provide solutions which can easily be used and its functions understood. Information and education need to be an integral part of the market introduction of new technologies. Technology providers should not be looking at just solving one issue, but looking at producing comprehensive and integral solutions that are able to solve more issues at one go. On this subject an approach is recommended to provide solutions that are resilient to future developments and take the entire lifecycle of the building into account. This is a factor that is prevalent in tropical climates. Needless to say that all solutions need to be based on "green" technologies and must aim to fit in a circular economy. Final objective is to find solutions to contribute to healthy, comfortable, zero energy buildings in green and smart cities.
2. Combined market introduction to capacity building

   Market introduction for installations and after salesservice of new technologies require great care and poses a challenge to the adaptation into the existing market fabric. Starting in small market volumes, the capacity in the supply chain needs to be developed to serve a fast growing market deployment. In many cases higher installation cost, training cost, continuous need for upgrades, policy hurdles, dissemination to the building professionals and specialized after sales service need to be addressed. Simultaneously the maintenance aspect of the technology need to be developed. Localized availability of spare parts, hardware support for technology upgrade need to be in place for a scaling up the deployment of new technologies and solutions. In order to provide localised technological solutions, a sound and robustly funded R&D infrastructure is required as well as an effective collaboration between the research community and industry.

3. Consumer acceptance and technology confidence
   Technology, in order to be widely accepted, needs to be user friendly and low cost to reach masses. Wide acceptance of technological solutions is needed to reach energy conservation and climate goals. User-friendly technologies address the usability as it is meant for people to use it. A low-cost technology can ensure that it can be widely implemented (even in emerging economies). Furthermore, consumers need to feel confident by the new technology. This requires avoidance of failures, comfortable use (no noise) and healthy indoor climate and trusted standards.
   Testing is essential so that technologies are performing up to the intended standards, certification schemes and design criteria and fulfill the requirements of the clients.
4. Acceptable business case and level playing field
   Technology must be priced reasonably so that it is affordable to implement and will lead to a positive business proposition to the user. It requires a reasonable return on investment based on energy savings and capitalised cost for improved comfort. In many regions in the world, the non-renewable energy sources are still cheaper than renewable sources and lack a level playing field. As a result incentive programmes may be needed to support the market growth of new energy saving and renewable solutions.

5.3 Challenges – Technology Implementation

Reported by François Garde

The participants on this theme have identified several key challenges and barriers to deploy technology implementation. These include:

1. Lack of finance:
   The availability of finance to deploy and test technology under market conditions and needs are lacking.
2. Bringing from prototype to mass market:
   There is a period of prototype commissioning and testing before the technology is appropriately optimized and ready for the mass market.
3. Integration of systems into existing infrastructures: Building owners are reluctant to be the first one to integrate new technology into their building infrastructures.
4. Layout of the buildings within the city can make testing technology challenging. Sometimes technologies that focus on passive design are more readily received than active systems.
5. Need to design comfortable buildings with low environmental impact.
6. Change the mindsets of building occupants on the use of new technology and the respective merits.
7. Require the availability of data from existing cities to better plan for future projects.
8. Complexity of new technology and their maintenance requirements may make building owners reconsider their positioning of adopting new technology.
9. Designing comfortable buildings with low environmental impact
10. Cultural barriers
11. Due to the introduction of more efficient products to the market, there is bound to be pressure from competitors who have technology that is more mature in the market.
12. Some building infrastructure is not properly commissioned. As a result, new technology cannot be easily incorporated and deployed.
13. The design of the technology has to be versatile enough to allow consumers to adjust to their needs and preference.

In parallel, the participants on this theme have also identified several potential avenues to overcome or reduce barriers to deploy technology. These include:

1. Provide essential guidelines to consumers on how to use the technology
2. Development of more demonstration projects to demonstrate the benefits of the technology. These can be at neighbourhood and building scales.
3. Provide more support for simple projects that can be more easily replicated at large scale.

4. Education is a very important element to reduce barrier to deploy market-ready technology. This includes sharing of ideas and experience coupled with new approach of teaching consumers the value-add of these new technologies to improve their daily operations.
5. There must be funding available for the right projects even at the design and testing stages. In other words, funding agencies must be more willing to take risks.
6. Available training to raise the competency of the end-users is critical to ensure they are able to conduct basic maintenance of the technology.
7. Government has a key role to play to influence the introduction of the technology to the market and in addition to encourage adoption by end-users.

5.4 Opportunities – City and District Level: Policy, Market and Technology Aspects

Reported by Mark Spurr

Local political leadership is a powerful factor in development of practices and systems for sustainable cities. Education of political leaders and policymakers can be a powerful tool, helping local leaders see what is possible, understand the opportunities, challenges and benefits of sustainable energy systems, and learn how to evaluate, plan and implement sustainable practices and systems.

Local leaders can also help their communities shift the mindset regarding energy from "energy supply and demand" to focusing on the services that result from energy use (mobility, comfortable indoor environment, etc.). This can facilitate creative ways to meet the real needs of the community more sustainably.

Cities can play a crucial role by developing the city-wide planning and policy framework for sustainability. Such a framework must be far-sighted and may include:

- Standards and regulations affecting the design and operation of buildings;
- Zoning affecting the mix of building spaces within districts, as well as the potential access to low carbon waste heat or renewable energy sources;
- Integration of infrastructure systems (potable water supply, wastewater treatment, municipal solid waste, electricity, cooling, natural gas) to create synergies, e.g. reducing carbon emissions by using output from one system to supply another system, or reducing costs by installing all street utilities at the same time;
- Assessment of opportunities for district cooling based on thermal load density and local opportunities for low-carbon cooling sources;
- Integration of electric vehicles and self-driving vehicles relative to grid/vehicle charge and discharge, space allocation for building access and parking, etc.; and
- Planning for, and potentially mandating use of, district cooling systems, mass transit or other low-carbon technologies in high-density districts or corridors.

City sustainability plans should strive for a "circular economy" in which community energy, water and other resource requirements are obtained to the greatest possible extent from sources produced within the community.

Planning on a district level, within the city-wide sustainability framework, can take place based on the timing and pace of new development or retrofits. Mixed use districts (combining office, residential, retail, and potentially certain industrial uses) can enhance sustainability in multiple ways, i.e.:

- Reducing transportation requirements through co-location of housing, jobs and shopping;
- Improving load diversity, which reduces peak electricity and thermal energy demands and thus requires smaller electric and thermal district grids; and
- Facilitating beneficial use of waste heat (e.g., use of reject heat from cooling to heat domestic hot water, or use of industrial waste heat to produce cooling through absorption chillers).

District planning will be customized based on the specific characteristics of the district and the merits of district-specific systems vs. use of city-wide infrastructure. District systems should be implemented in districts where such systems provide strong sustainability benefits cost-effectively. District system development generally takes place based on uptake of customers through long term contracts, but the business model of the implementing entity may take many forms, e.g. city-owned, private non-profit, private for-profit, public-private partnership, etc.

Information technology generally and AI particularly holds promise for a range of opportunities for enhanced sustainability, potentially affecting future work-home relationships, reduced energy consumption through enhanced controls, and optimized recovery of waste heat and renewable energy sources.

Human behaviour has a strong impact on use of energy, water and other resources, and it is important to communicate with and provide information to consumers during the planning process (i.e. refurbishing of districts, discussions on improvements) as well as during ongoing use of utility systems.

5.5 Opportunities – Building Level: Technology Needs and Solutions

Reported by Tham Kwok Wai

We must not forget the reasons for designing buildings, hence it is important to first define the Needs and expectations. These include:

1. Considering the different climates and seasons prevalent in the country and avoiding inappropriate technology / design habits transfer from other climates. Need for more data for tropical climates e.g. daylight designs appropriate to the tropical climate. Integrating different technologies that can suit the different weathers and seasons e.g. combination of cross ventilation, AC and ceiling fans
2. Focusing on half of the world's population who cannot afford air conditioning. Considering passive design, especially for non-AC buildings
3. Factoring the environment around the building
4. Integrating smart control into building systems so that buildings is responsive and adaptive to both internal and external factors / situations
5. Balancing thermal comfort versus indoor air quality
6. Focusing on the energy efficiency of the building over the lifespan of the building

For building technology solutions, the group discussed the following:

1. Need to take note of complacency from designers and providing training to improve technology awareness and increase competency of designers
2. Improve the planning stages by engaging architects and engineers to work hand-in-hand
3. Building facades should be designed beyond thermal insulation e.g. dynamic façade, shading and day-lighting
4. Usage of building materials other than conventional building concrete
5. Injecting nature into buildings / biomimicry and integration of greenery
6. Integrating with systems (e.g. application of AI to assist occupants and operators to provide better control and integrating smartness)
7. Influencing management of plug loads
8. Instead of HVAC, use low energy dehumidification technologies for removal of moisture compared to lowering temperature
9. Need to consider context as well especially for countries with very high temperatures
10. Hybrid Ventilation / Cooling by switching off the AC whenever passive cooling or natural ventilation solutions are adequate to ensure that the temperature falls below the required set point (different technology for inverted and non-inverted ACs)
11. Being mindful that sometimes more efficient systems have higher embodied energy and greenhouse gases than lower efficiency systems
12. Reusing rejected waste heat from current air-conditioning systems / reuse of condensate from the air-conditioning system
13. Reducing demand versus reducing supply from fossil fuels
14. Engaging occupants and operators to reduce wastage of energy

5.6 Opportunities – Building Level: Policy and Market Implementation

Reported by Stanford Harrison

Four of the most critical challenges and examples of them were identified as follows:

1. Evaluation of energy policies and decision-making based on evidence of energy and non-energy benefits:
   Evaluation of energy policies in terms of energy and non-energy benefits is rare;
   Very little hard evidence exists on non-energy benefits outside emission reduction;
   Engaging people to understand energy and non-energy benefits is complex and difficult to communicate;
   Financial framework is a topic to be addressed by policymakers as decision-making does not necessarily reflect energy and non-energy benefits and there are important financial barriers to the realization of these benefits in buildings.
2. Energy prices when taking into consideration actual cost of externalities reducing the impact of price signals to the market:

Policies are disconnected for energy supply sector and the building sector;

Energy prices often do not express their actual cost including environmental externalities.

3. Consider human behaviour such as people's change and acceptance (note: some are climate dependent) as well as market failures:

   Human behaviour does not change so easily and affects adoption of new technologies and practices;

   Occupant behaviour has a big impact on building energy use;

   Multiple stakeholders can slow decision making, generate conflicts of interest;

   Split incentives between builders and developers who pay the capital cost of energy efficiency, and later owners, occupiers and tenants who benefit from lower energy use;

   Split incentives between landlords and tenants.

4. Market building and capacity building for building energy efficiency:

   Investments for clean energy and low carbon solutions require both a market demand and depth of expertise to meet that demand;

   Authoritative, clear, evidence-based guidance material can be lacking for new technology and new approaches;

   There are many barriers to bringing new technology to market;

   Building and technology solutions vary with climate and require optimization (e.g. hot and humid climates have different demands on cooling technology).

Solutions:

Development of three pillars of solution that potentially address aforementioned challenges.

1. Technology:

   Roadmaps for the development of new building energy efficiency solutions provide an ongoing framework i.e. Roadmaps as a framework to drive solutions;

   Promotion of technologies availability aids market and capacity building;

   Development of authoritative, clear and evidence-based guidance material greatly aids development and deployment of new technology.

2. Stakeholders:

   Promoting best practice in government policies (e.g. IEA to engage with governments and supporting policies; IEA to host / coordinate low carbon communities (cities) in the tropics);

   Creating policies that enable investments and overcome market barriers;

   Valuation of creating evidence-based policies with more comprehensive coverage of both benefits and costs;

   Marketplace decisions / creation / engagement is facilitated by enabling financial institutions and decision makers to understand the evidence;

   Form relationships first and the implement change later by selling services;

   Need for policies to fund R&D to enable development and deployment of better solutions;

   Capacity building (e.g. pay the actual cost of capacity provided to buildings).

3. Regulations and government action:

   Building codes are a key solution to improving building energy efficiency by overcoming market barriers such as split incentives;

   Cities can take more leadership in policies and stretch targets as well as promote exemplary solutions (e.g. Copenhagen);

   Government purchasing power and bulk procurement (e.g. bulk purchasing of energy efficient products) can develop markets;

   Government can demonstrate leadership in setting standards for government buildings and social housing;

   Policies enabling investment (e.g. green estate investment fund, green bond) drive market building and capacity building;

   Investment in R&D activities enables development and deployment of better technologies and solutions;

   Integration of subsidies into the building codes;

   Government energy subsidies mask price signals for efficient energy use and should be rationalised;

   Let the marketplace make energy purchasing decisions based on the full cost of energy including externalities, so that price signals are fully effective

   Outcome-based regulations such as mandating building rating systems provide data for evidence based decision making, address market barriers and aid market building and capacity building;

   Active information exchange and cross use of knowledge to promote effective policies;

   Active international cooperation such as through IEA technical collaboration programs promotes effective dissemination, efficient standardization and facilitates uptake and deployment of better technology and solutions in building energy efficiency around the world.

5.7 R&D Priorities – Building HVAC and Systems

Reported by Tham Kwok Wai

For potential R&D for building HVAC and systems, the group discussed the following:

1. Awareness of limitations of the energy efficiency of HVAC systems, should also look into reduction of parasitic consumption
2. For dehumidification – research on material (e.g. hydrogel or silica material) and integration with solar thermal for regeneration of the material
3. Focus may be on radiant and natural convectional cooling technologies. For passive displacement ventilation system:
   Current designs based on experience of experts, need for design guidelines/standards;
   Can refer to REHVA and ASHRAE guidelines from overseas;
   Improvements to passive displacement ventilation systems as a) Current system may trap certain viruses or bacteria, b) Re-evaluate thermal comfort guidelines, and c) Lower cooling load but still feeling thermal comfort.
4. Consider distributed chilled water pump technology to replace control valves – knowledge and skill that needs to be developed
5. Over-design of coils – can we have technological innovation to foster adaptability of the coils for optimum performance across part load conditions?
   Modulation, flow rate, temperature, and area of coil.
6. Consider recovery of waste heat from current Air-conditioning systems (for hot water)
   Government intervention can improve current situation;
   Implementation of guidelines and standards (IEA HPT Annex 39 governs the efficiencies of combined systems);
   Heat recovery systems can work under most circumstances.
7. Recognition of diversity between individuals – can the future AC system respond to diversity of individual needs such as personalized AC?
   Customized and responsive system (as and when needed);
   Change the way we design AC distribution systems;
   Tap on IoT systems as a facilitator.
8. Rethink offices – How to improve current thermal comfort systems – consider air quality and the amount of fresh air into the building. Building systems to consider outside weather in conjunction with the inside conditions. Develop performance indices that holistically characterize indoor environmental requirements.
9. Develop a framework for all passive technologies and how they can be applied to different situations. Consider the type of envelope of the building. Does natural ventilation work for residential / public housing, or is mechanical outdoor ventilation required as a substitute to reduce the ambient temperature alternatively or in conjunction of AC cooling (e.g. Homes provided by the Singapore Housing and Development Board)?
   80% of current homes have split units installed; Consider district cooling instead due to economies of scale?
10. Building automation and sensors:
    Include modularity into building systems;
    Sensors to replace set points;
    Improve occupant and operator control over systems;
    To make the systems more user-centric;
    Current sensors either too accurate / inaccurate: a) Develop catalogue and classification of sensors to show accuracy and reliability, b) Allow occupants and operators to make better informed decisions;
    Should look into IoT (e.g. Digital Ceiling by CISCO) to respond as, where and when needed;
    Currently, advocating use of various sensors in one system to provide more accurate occupancy rates. Addition of AI to control based on occupancy levels;
    Cost in market will usually be driven down depends on a) Profit-driven mindset, or b) Consumer mindset.
11. M&E Consultants to be enlightened by being involved in the design of hybrid systems
12. Data Centers consuming 20% of total building energy consumption:
    Cooling techniques – at the microchip level, us of other technologies (e.g. heat pump and absorption chillers). Recovering heat requires large area which could pose a challenge. Consider evaporative cooling/ free cooling;
    Low grade temperatures in DC - consider heat pump technology to lift the temperatures to recover energy into electricity using Organic Rankine Cycle (ORC).

5.8 R&D Priorities – Building Envelope and Occupant Behaviour

Reported by Ricardo Enriquez Miranda

Based on discussions, the following R&D needs in topic "Building envelope and occupant behaviour" have been formulated:

1. Critical R&D needs in tropical and sub-tropical countries
2. Business cases in various climate zones with successful integration of PV / solar thermal (ST) systems, active façades, and smart controls to be accepted by industry and policy makers
3. R&D on AI to optimize specific aspects of building operations and improve occupant comfort (for all type of buildings)
4. Knowledge and technical capacity:
   Need in building the capability of scientist / building experts in ASEAN countries through collaborative, cross climate research projects, internships, and trainings to adopt best practices for sustainable building envelope design;
   R&D on appropriate modelling techniques for active façades and cross integration of passive techniques;
   R&D on bioclimatic buildings and BEMS optimization in various climatic zones.
5. Knowledge of occupant-behaviour:
   R&D on occupant behaviour towards individual controls versus automated / smart / predictive controls (i.e. shading devices versus automated blinds) as energy efficiency and conservation measures in range of the occupants' groups / countries / economies / cultures;
   Development of best practices to enhance the sustainability of occupants (education / engagement / shift of the mind-set);
   Development of smart devices / apps for reliable communication between building envelope systems, sensors, services, and occupants;
   Need in development of advanced integrated state of art software for smart and predictive controls for cooling load, lighting, and appliances;
   R&D of impact of social groups and occupant types on energy pattern (working adult / non-working adult / senior / children in various age groups). Development of database for future enhancement of demand/ supply pattern and prediction control practices. Building envelope and system integration;
   R&D on optimization of façade and building envelope design for hot and humid climates not limited to daylight / glare control, heat rejection, and thermal comfort;
   R&D on optimal passive design for active façades in hot and humid climates, especially appropriate design of natural or mechanically ventilated air-conditioned spaces in different building types (thermal impact, novel building materials);
   R&D in thermal performance assessment and certification / standardization of building materials, and envelopes in all climate zones;
   R&D on integration into building envelope various PV technologies / solar thermal / other systems (optimization: efficiency, thermal comfort, business cases / test beds);
   R&D focus for particular country needs and economy standing i.e. efficient and affordable mass public low or high-rise housing;
   Evaluation of building performance of existing building types by including the socio-economic aspects and post occupancy evaluation (POE).

5.9 R&D Priorities – City and District Scale

Reported by Ho Hiang Kwee

1. Optimize use of limited space in high density and high cost real estate:
   Compact thermal energy storage, e.g. phase change materials (PCMs);
   Novel PCMs that operate at higher temperature level about 17°C - 19°C for low exergy systems.
   Circulate ultra-low temperature fluid.
2. Water Saving strategies:
   Technical and regulatory strategy for using TSE (treated sewage effluent) for condenser cooling (cooling tower);
   Potential use of grey water.
3. User-friendly flexible analysis models and guidance for planning and design of integrated infrastructure (cooling, electricity, natural gas, waste water treatment, potable water, mobility)
4. Demonstrate state of the art of district cooling as well as integration of technologies to provide different services:
   analyzing data collected to validate and refine analysis models and toolsprovide evidence for policy makers;
   provide evidence for policy makers.

5. Reducing negative impacts of high density on such effects as reduced day lighting, heat island effect and impacts on natural ventilation
6. Generate energy through low carbon sources
7. Capacity building for holistic / integrated Urban planning (incorporating energy, water, land and food)
8. Involve market and policy experts
9. Design with sensitivity to cultural and social impacts

5.10 R&D Priorities – Grid and Storage Interaction, Renewable Integration

Reported by Stephen Tay

In the focus discussion group for "Grid Storage Interaction, Renewable Integration", the scope of renewable energy was mainly focused on solar photovoltaic and wind. The discussion can be categorised into the following aspects:

1. Technical aspect: From the technical aspect, the group agreed that with the introduction of renewable sources of energy, intermittency of renewable power generation presents an issue that deserves attention. This is so as grid stability and power quality may be affected as fluctuations in renewable power generation occur. The members have also pointed out that some countries may have plans to construct a single national grid to deliver renewable energy in high resource areas to low resource areas. Such plans would have to consider the stability of the unified grid with renewable generation as well.
2. Occupant behaviour: Another point that was discussed was occupant behaviour. The load imposed on the grid is determined by the users of the grid. Hence, if building occupants can be encouraged to use electricity during certain periods of time, the load on the grid can be alleviated.
3. Regulatory: Other than the aspects discussed above, the group has also pointed out regulatory aspects which should be considered, especially in countries where various states within have different requirements and regulations for power quality and grid standards.
4. Financing: The issue of financing was also discussed as cost of transmission line upgrades and inclusion of storage in renewable energy systems could be cost-prohibitive. The issue of "who should pay for the grid connection / upgrades" was also raised during the discussion of an example where a renewable energy project developer would like to install a solar / wind farm, but the grid is not technically capable of accommodating the project. Therein then lies the question of should the developer of the grid owner pay for the grid upgrade.
5. Aggressive bidding and skilled expertise: In addition to the points above, the matter concerning aggressive bidding of renewable projects and skilled expertise was brought up. The group pointed out that competitive projects sometimes bid with a low tariff, which may not include the cost of storage. Such aggressive bidding would drive benchmark tariffs lower that may not be reflective of total system cost. The lack of skilled expertise in regions that are beginning to embrace renewable energy projects would require involvement of overseas consultants, which will increase the overall project cost.

   After the five broad categories were identified, the group began to deliberate on the R&D areas that warrants attention. Among the five categories identified above, prioritisation and emphasis for grid storage interaction and renewable integration was made on the first two categories (technical aspects and occupant behaviour).

   The following points below highlight the potential R&D areas in response to the technical aspect (Items 1 to 9) and occupant behaviour (Items 10 to 12).

Technical aspect – Storage:

1. Storage as an intermediary: As an intermediary between the renewable plant and the grid, storage could absorb excess renewable energy generated that could otherwise introduce grid instability. Storage could also enable fast response to variable customer loads, thereby reducing the strain on the grid.
2. Investigate lifetime and performance of renewable energy systems coupled with batteries in hot and humid climates: As more renewable energy systems are coupled with storage in the tropics, how the ambient temperature of the battery affects the lifetime and performance of the coupled system would be an important relationship to be established.
3. Modelling and simulation studies of varying levels of renewable energy penetration into the grid with and without storage: One major concern of grid operators that was shared by the group members lies in the issue of renewable energy intermittency, which will affect grid stability and power quality. With a higher penetration rate of renewable energy in the energy portfolio (with and without storage), modelling and

simulation studies of future grid scenarios with varying renewable energy penetration rates would provide grid operators a better understanding of the potential effects on grid stability and power quality, which will enable them to react and deploy mitigation measures.

4. Alternative battery technologies: The current widespread use of lithium-based batteries have raised concerns of flammability and potential scarcity of the element. The issue of flammability is even more pertinent for deployments in hot and humid environments, while the scarcity of lithium in the earth's crust poses a potential challenge to long-term supply of storage with the said element. Hence alternatives based on materials that are abundant in the earth's crust, as compared to the rarity of lithium, could be looked at to ensure a long-term supply of batteries based on such technologies. Furthermore, battery materials that are stable in hot and humid environments could also be looked at.

Technical aspect – Grid:

1. Green corridors: In countries with several states, regions with dedicated transmission lines to transport of renewable energy generation from regions of high renewable resource to regions with low renewable resource could be looked into. The deployment of such regions could be simulated with the loads of the various states considered.
2. Formulation of a national level blueprint for grid standards in countries with various states: In countries with several states, there may exist an ecosystem where the various grid operators abide by different standards in the different states. Such differences in standards would pose a challenge to move towards a unified national grid, which will allow the various grid participants to adhere to a single standard, which will aid in the integration of the various networks. Hence the group recommended for such countries to have a national level blueprint for the various participants in the grid network to follow.
3. Study big data obtained from energy (generation and consumption) meters: Data obtained from electricity retailers would be beneficial to understand the city / state / country's load demand. With the load demand understood, the integration of renewable energy, and its intermittent nature, could be managed better. The move towards electric vehicles could also be an interesting source of "mobile batteries", where the charging of such vehicles can be analysed through meter readings and explored if these sources of electricity could act as potential batteries. The group recognises that personal consumer data protection is an issue and needs to be respected with permission obtained for such studies.
4. Resource forecasting: Predicting the resource level of irradiance and wind would not only allow grid operators to better manage their generators' ramp rates to maintain grid stability in cases of high / low renewable energy production, but also allow renewable energy asset operators to better price the risk of intermittency in their financial planning.

Occupant behaviour – Pilot projects:

1. Conduct pilot projects to understand consumer interaction with grid loads: Participants could be encouraged to use their loads at times when demand is low to shift demand, which could be achieved through time-of-use pricing as an example. This could potentially reduce peak demand load on the grid. Such studies should also consider the degree of retention of acquired positive behaviour after the duration of the pilot to understand the effectiveness of the program.
2. Modelling and simulation of various occupant behaviours on the grid: A variety of occupant behaviours on the grid (staggered laundry habits or scheduled charging of electric vehicles) could be designed with its effects on the grid simulated. This will enable policies encouraging behaviours with the targeted benefits to be identified and implemented, which will reduce grid load.
3. Development of a standard methodology for various countries: Participants in studies involving occupant behaviour on grid demand would need to adhere to a common methodology to allow comparisons to be made across countries. This will enable useful policies which worked in a certain city / state / country to be implemented into another city / state / country of a similar environment.

Occupant behaviour – New transaction modes:

1. Peer-to-peer transactions using block chain: With the advent of block chain technology as a transparent database with low transaction costs, the technology has the potential for peer-to-peer electricity trading at affordable prices for consumers. The design and execution of such a system in small communities could be looked at, along with the uptake and consumer response. This would encourage new business models to be designed, which may improve market efficiency.

6. CONCLUSIONS

Throughout the two-day forum, the importance of passive design was constantly emphasised as the key to reduce energy required for cooling not only for the tropics. By addressing the envelope to minimise heat transfer into the buildings and leveraging on natural (or, in absence mechanical outdoor) ventilation to cool the spaces, less dependency on air-conditioning is required. Therefore, there is a need to revisit the design and planning guidelines for architects, consultants and even developers to place more emphasis on passive strategies to minimise cooling loads and energy consumption.

On the other hand, it is also important to highlight that this approach may not be suitable in offices and retail sector, although some of the common spaces can still be naturally ventilated. This is where the choice of suitable and efficient air-conditioning systems come into play. The use of hybrid cooling (minimising cooling from air-conditioning systems and using fans to help with increasing local air speeds) is gaining acceptance in some of the development in the tropics. This helps to reduce the overall energy demand for cooling. Another area which is gaining importance is to decouple the latent cooling and sensible cooling. These different solutions where both humidity and airflow contribute to improving the "apparent temperature" of the occupant.

The net-zero energy concept was featured in the presentations to challenge developers and consultants to increase the overall building energy efficiency level and offsetting the energy demand through the generation of electricity using renewables. Not only does it help to reduce air-conditioned spaces in its design, but the ZEB concept focuses on the importance of thermal comfort and

Figure 7: Plenary session

occupant behaviour. The use of AI and data analytics will help to understand occupancy patterns and preferences, and optimise systems in what we foresee as the future of smart buildings.

In high-density areas in the tropics, district cooling systems can enhance sustainability by tapping low-carbon energy sources, increasing the efficiency of electricity use and optimizing use of treated sewage effluent.

There was much discussion regarding policy and market barriers to implementing low-carbon technologies. Prices for energy and water generally do not reflect their full economic and environmental costs, and as a result we do not have the right price signals to encourage existing low-carbon approaches through market mechanisms.
R&D programs should involve market and policy experts to develop recommendations for market reforms or other policies to encourage the planning, financing and implementation of low-carbon technologies; and case study examples, information and analysis tools addressing the benefits of integrated infrastructure systems (electricity, cooling, potable water, wastewater, solid waste).

The discussions on the R&D priorities have surfaced a laundry list of possible areas of research for the respective TCPs to select and define the research work for their respective strategic plans for the next 5 years. As the theme is focused on hot and humid climates, it would be encouraging to see greater participation from countries in the tropics in the R&D work undertaken, or even to lead some of this work.

As there was no other business, the two co-chairs Andreas Eckmanns and Tian Chong Tan closed another successful Future Buildings Forum Think Tank Workshop with many fond memories of friendship forged during these two days.

7. APPENDIX

7.1 Appendix 1 – IEA Future Buildings Forum Think Tank Workshop 2017 Advisory Board

An Advisory Board comprising of members from each of the International Energy Agency buildings-related Technology Collaboration Programmes was formed to provide advice on the format, content, list of speakers and participants for the Workshop.

The Advisory Board was chaired by Andreas Eckmanns, Chair IEA EBC and the Internet meetings were organised by the host Mr Noel Chin, Building and Construction Authority.

1st Meeting (11th July 2017)

Organisation	**Participant**
Chair, IEA EBC	Mr Andreas Eckmanns
Secretary, IEA EBC	Mr Malcolm Orme
Operating Agent, IEA-DHC	Mr Andrej Jentsch
Chair, IEA-HPT	Mr Stephan Renz
Chair, IEA-SHC	Mr Ken Guthrie
Executive Committee Member for Spain, IEA-SHC	Mr Ricardo Enriquez
Chair, IEA-PVPS	Mr Stefan Nowak
Vice Chair, 4E	Mr Mark Ellis
Vice Chair EUWP and Chair BCG	Ms Sabine Mitter
Desk Officer, IEA Secretariat	Mr Brian Dean
Host FBF 2017, Singapore	Mr Noel Chin

2nd Meeting (29th August 2017)

Organisation	**Participant**
Chair, IEA EBC	Mr Andreas Eckmanns
Executive Committee Member for Australia, IEA EBC	Mr Stanford Harrison
OA, IEA-DHC	Mr Andrej Jentsch
Chair, IEA-HPT	Mr Stephan Renz
Chair, IEA-SHC	Mr Ken Guthrie
Chair, IEA-ECES	Mr Teun Bokhoven
Chair, IEA-PVPS	Mr Stefan Nowak
Vice Chair, IEA End Use Working Party, and Chair, IEA Buildings Coordination Group	Ms Sabine Mitter
Executive Committee Member for Italy, IEA EBC	Mr Michele Zinzi
Desk Officer, IEA Secretariat	Mr Brian Dean
Host FBF 2017, Singapore	Mr Noel Chin

7.2 Appendix 2 – Session Plan

Day 1, 24th October 2017

Time	Duration	Activity	Venue
0830	*30 mins*	*Registration and breakfast*	T1-1 Auditorium
0900	*30 mins*	**Welcome and opening address** – Welcome: *Mr Tan Tian Chong, Dy Managing Director Built Environment Research and Innovation Institute, BCA* – Welcome: *Mr Keisuke Sadamori, Director Energy Markets and Security, IEA* – Opening: *Mr Andreas Eckmanns, Chair IEA EBC*	T1-1 Auditorium
0930	*30 mins*	**Keynote** "Future challenges of cities in hot and humid climates" *Prof Lam Khee Poh, Dean School of Design and Environment, National University of Singapore*	T1-1 Auditorium
1000	*20 mins*	*Tea-break*	Tower Block, Level 2 Foyer
1020	*100 mins*	**Challenge Statement** Plenary presentations on – Policy: "IEA Energy Technology Perspectives" Brian Dean, Energy Efficiency Division, IEA – Industry and Business' view: Christian Holter, SOLID – Future challenges of cities: "Sustainable, resilient and low carbon" Deo Prasad, Low Carbon Living CRC – Technology/Implementation: – "Zero Energy Townships in Vietnam, a Macro-Economic Perspective" Poul Erik Kristensen, IEN Consultants – "Singapore's Positive/Zero/Super-Low Energy Buildings Challenge for the Tropics" – Dr Gao Chun Ping, Director Green Building Research Department, Built Environment Research and Innovation Institute, BCA – "The Building Efficiency Accelerator and its work in cities" Sumedha Malaviya, WIR	T1-1 Auditorium
1300	60 mins	*Lunch*	Block F, Cafeteria
1400	90 mins	**Challenges to be addressed** *Barriers and obstacles in policy making and implementation, business and market penetration, technology uptake and in addressing occupant behaviour* Guided parallel discussions in 3 groups to cover the perspectives of i. Policy Making and Implementation (Government / Authorities) ii. Technology Meets Market Demand (Industry) iii. Technology Implementation (City / Planners / End-users)	T8-3, T8-4, T8-5
1530	30 mins	*Tea Break*	Tower Block, Level 2 Foyer
1600	30 mins	Conclusions from the Parallel Sessions on Challenges Identification of 12-16 topics including cross-cutting issues to be further discussed (e.g. rating by participants). Presenters from each of the 3 groups	T1-1 Auditorium
1630	30 mins	Industry Keynote "Importance of long term measurement and monitoring for ACMV in the tropics" Mr Lee Eng Lock, Deputy Chairman and Senior Technical Director, Measurement and Verification Pte Ltd	T1-1 Auditorium
1700	30 mins	Travel to United World College of South East Asia (UWCSEA) for Site Visit	

1730	*45 mins*	**Site Visit** United World College of South East Asia (UWCSEA) Dover Campus "3for2" technology. Transportation provided from BCA Academy.	UWCSEA Dover Campus, Admin Building
1815	*30 mins*	**Travel to NUSS Guild House@Suntec City for Networking Dinner**	
1900	*180 mins*	**Networking Dinner** (Paid event). Transportation provided from UWCSEA Dover Campus	NUSS Guild House@ Suntec City

Day 2, 25th October 2017

Time	**Duration**	**Activity**	**Venue**

0930	*90 mins*	State of the Art briefings
		Plenary presentations out of the TCPs network
		– Cooling Technology:
		  – "Cooling Technologies" – Stephan Renz, Chair IEA HPT
		  – "Solar cooling" – Stephen White, IEA SHC
		– Building Efficiency:
		  – "Ventilative Cooling – Activities towards Future Buildings" (IEA EBC Annex 62) – Dr Nonaka Toshihiro
		  – "Multi-Scale Energy Systems" – Dr Jimeno Fonseca, ETH-FCL
		– Grid and Storage Interaction:
		  – "Policies for encouraging Low Carbon Cooling in hot, humid climates" Mark Spurr, IEA DHC
		  – "Energy Storage" Teun Bokhoven, Chair IEA ECES
		– Policy Implementation:
		  – "IPEEC and G20 updates" Stanford Harrison (tbc)
		  – "Mission Innovation Affordable Heating and Cooling Challenge" Stephen White, IEA SHC
		– User Centric Approach:
		  – "IEA EBC Annex 69 Adaptive Thermal Comfort, Dr Yao Meng
			T1-1 Auditorium

1115	*15 mins*	*Tea-break*	Tower Block, Level 2 Foyer
1130	90 mins	Opportunities Identify the means to address the existing challenges in the fields of technology, policy and market implementation Guided parallel workshop discussions (3 groups of which each works on 3-5 topics as identified on Day 1) i. City and District level – technology needs and solutions/policy and market implementation ii. Building level – technology needs and solutions iii. Building level – policy and market implementation	T1-1 Auditorium
1300	60 mins	*Lunch*	Block F, Cafeteria
1400	30 mins	**Conclusions from the parallel Sessions on Opportunities** Findings of the 3 groups and assignment of these for in-depth discussion in the following discussion blocks (afternoon session). Presenters from each of the 3 groups	T1-1 Auditorium

1430	90 mins	R&D Priorities of the next 5 years In-depth discussion on where and how IEA TCPs contribute to provide solutions, as well as prioritisation of each R&D theme. Guided parallel workshop discussions (4 groups of which each works on 3-5 topics including cross-cutting issues) i. Building HVAC and systems (HPT, 4E, EBC, SHC) ii. Building envelope and occupant behaviour (EBC, SHC, DSM, PVPS) iii. City and District scale (DHC, EBC, DSM, ECES, SHC) iv. Grid and storage interaction, renewable integration (ISGAN, ECES, PVPS, SHC)	T8-1, T8-3, T8-4, T8-5
1600	30 mins	Tea break	Tower Block, Level 2 Foyer
1630	30 mins	Conclusions from the parallel Sessions on R&D Priorities Identification of R&D priorities of the next 5 years Presenters from each of the 4 groups	T1-1 Auditorium
1700	30 mins	Wrap-up, follow up actions and closing remarks Conclusions and recommendations resulting from the FBF 2017 Co-chairs	T1-1 Auditorium
1715		**End of the meeting**	T1-1 Auditorium

7.3 Appendix 3 – Participants

Participants from IEA buildings-related Technology Collaboration Programmes (TCPs)

Organisation	Participant	Country	TCP
BEAR-iD	Mr Tjerk Reijenga	The Netherlands	PVPS
Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Dr Stephen D White	Australia	EBC
Cukurova University	Prof Halime Paksoy	Turkey	ECES
Department of the Environment and Energy	Mr Stanford Harrison	Australia	EBC
IEA EBC Executive Committee Secretary and AECOM	Mr Malcolm Orme	UK	EBC
Effin'Art	Mr Pierre Jaboyedoff	Switzerland	
Energy Science Center	Dr Christian Schaffner	Switzerland	
ETH-FCL Singapore	Dr Jimeno Fonseca	Singapore	
ETH-FCL Singapore	Mr Bharath Seshadri	Singapore	
Federal Ministry of Transport, Innovation and Technology / IEA EUWP Vice Chair	Ms Sabine Mitter	Austria	EUWP
FVB Energy Inc	Mr Mark Spurr	USA	DHC
Greentech Knowledge Solutions Pvt. Ltd.	Dr Sameer Maithel	India	
IEA	Mr Brian Dean	France	IEA
IEA ECES Executive Committee Chair	Mr Teun Bokhoven	The Netherlands	ECES
IEA EUWP Chair	Ms Gudrun Maass	Germany	EUWP
IEA-HPT Executive Committee Chair	Mr Stephan Renz	Switzerland	HPT
IEA-SHC Executive Committee Chair	Mr Ken Guthrie	Australia	SHC
IEA-SHC Executive Committee Vice-Chair	Mr Riccardo Enriquez Miranda	Spain	SHC
IEN Consultants	Mr Poul Erik Kristensen	Denmark	EBC
LIXIL Corporation	Dr Nonaka Toshihiro	Japan	EBC
Ministry of Power, Government of India	Mr Arijit Sengupta	India	
IEA EBC Executive Committee Chair and Swiss Federal Office of Energy (SFOE)	Mr Andreas Eckmanns	Switzerland	EBC
Netherlands Enterprise Agency	Dr Rob R.P Kool	The Netherlands	DSM
Politecnico di Torino - Department of Energy	Dr Marco Perino	Italy	EBC
SOLID	Dr Christian Holter	Austria	SHC
Swe. Refrigeration & Heal Pump Association	Mr Per Jonasson	Sweden	HPT
Tsinghua University	Dr Yao Meng	PR China	EBC
University College London	Prof Paul Ruyssevelt	UK	EBC
University of Brunei Darrusalem	Mr Jimmy Lim Chee Ming	Brunei	
University of La Reunion	Prof François Garde	France	SHC
University of New South Wales / Australian Cooperative Research Centre for Low Carbon Living	Prof Deo Prasad	Australia	
University of Wollongong	Prof Paul Cooper	Australia	
World Resources Institute India	Ms Sumedha Malaviya	India	
World Green Building Council	Ms Joelle Chen	Singapore	

Participants from the Singapore Community

Organisation	Participant
ASHRAE Singapore Chapter	Mr Patrick Ho
Beca Carter Hollings & Ferner (SEA) Pte Ltd	Ms Irene Yong
Bluevent Air	Dr Karl Wagner
Broad Air Conditioning	Mr Johnny Zhou
Building and Construction Authority	Mr Tan Tian Chong
Building and Construction Authority	Mr Ang Kian Seng
Building and Construction Authority	Dr Gao Chun Ping
Building and Construction Authority	Mr Jeffery Neng
Building and Construction Authority	Mr Selvam Valliappan
Building and Construction Authority	Mr Alvin Seoh
Building and Construction Authority	Mr Toh Eng Shyan
Building and Construction Authority	Mr Noel Chin
Building and Construction Authority	Mr Yu Liming
Building and Construction Authority	Ms Zhao Xijing
Building and Construction Authority	Ms Rohana Haron
Building and Construction Authority	Mr Majid Sapar
Building and Construction Authority	Mr Unni Krishnan Ambady
Building and Construction Authority	Dr Mano Sellappa
Building and Construction Authority	Mr Javier Tan
Building and Construction Authority	Ms Ng Shi Yu
Building and Construction Authority	Mr Roy Sim
Building and Construction Authority	Ms Goh Xinying
Building and Construction Authority	Mr Ryan Toh
CE Engineering Pte Ltd	Mr Tobias Gesch
Comfort Management Pte Ltd	Mr Lee Fatt Seng
DP Architects	Mr Lee Boon Woei
ETH- FCL	Ms Peng Yuzhen
ETH-FCL	Mr Jonathan Denis-Jacob
ETH-FCL	Ms Lea Ruefenahcht
ETH-FCL	Ms Hsieh Shan-Shan
ETH-FCL	Mr Gabriel Happel
ETH-FCL	Mr Shi Zhongming
ETH-FCL	Dr Sreephathi B Krishna
ETH-FCL	Mr Lukas Lienhard
ETH-FCL	Mr Constant Van Aerschot
G-Energy Global Pte Ltd	Mr Vincent Low
GreenA Consultants Pte Ltd	Ms Huang Yimin
GreenA Consultants Pte Ltd	Ms Laurenn Meghe
IEN-Consultants	Mr Gregers Reimann
Information and Media Development Authority	Mr Arvind Verma
Information and Media Development Authority	Ms Tay Yu Chan
Jurong Town Corporation	Mr Yee Peng Huey
Measurement and Verification Pte Ltd	Mr Lee Eng Lock
Measurement and Verification Pte Ltd	Mr Steven Kang
Ministry of Trade and Industry	Mr Subbaih Ramar
National Climate Change Secretariat	Mr Ho Hiang Kwee
National Security Coordination Secretariat	Dr Michele Chew

National University of Singapore	Prof Lam Khee Poh
National University of Singapore	Prof Wong Hyuk Nien
National University of Singapore	Prof Sekhar Kondepudi
National University of Singapore	Prof Ernest Chua
National University of Singapore	Prof Teo Ai Lin, Evelyn
National University of Singapore	Prof Lee Poh Seng
National University of Singapore	Dr Stephen Tay
National University of Singapore	Dr Veronika Shabunko
National University of Singapore	Dr Wei Meng Daniel, Sng
National University of Singapore	Dr Yeoh Ker-Wei
National University of Singapore	Dr Adrian Chong
National University of Singapore	Prof Tham Kok Wai
National University of Singapore	Dr Md Raisul Islam
National University of Singapore	Dr Lu Yujie
Ngee Ann Polytechnic EWT/COI	Mr Sam Lam
Ngee Ann Polytechnic EWT/COI	Mr Sunil Nair Saseedharan
Singapore Green Building Council	Mr Eddy Lau
Singapore Institute of Technology	Dr Chien Szu Cheng
Singapore Institute of Technology	Mr Steve Kardinal Jusof
Singapore Management University	Mr James Jian
Singapore Power Group	Mr Lim Song Hau
SOLID	Mr Patrick Soo
SOLID	Mr Andre Breuer

7.4 Appendix 4 – Participants of parallel discussions

Participants for parallel discussions on Challenges

Policy Making and Implementation (Govt / Authorities) Facilitator: Veronika Shabunko Secretariat: Javier Tan	**Technology Meets Market Demand (Industry)** Facilitator: Teo Ai Lin, Evelyn Secretariat: Ng Shi Yu	**Technology Implementation (City / Planners / End-Users)** Facilitator: Ernest Chua Secretariat: Roy Sim and Goh Xin Ying
Stanford Harrison	Patrick Ho	Tjerk Reijenga
Poul E Kristensen	Toshihiro Nonaka	Gabriel Happle
Sumedha Malaviya	Steven Kang	Shi Zhongming
Halime Paksoy	Yuzhen Peng	Bhargava Krishre Sreepathi
Paul Ruyssevelt	Jimeno Fonseca	Steve Kardinal Jusof
Mark Spurr	Sameer Maithel	Stephan Renz
Ken Guthrie	Karl Wagner	Francois Garde*
Yao Meng	Huang Yumin	Pierre Jaboyedoff
Deo Prasad	Laurenn Meghe	Gregers Reimann
Gudrun Maass	Teun Bokhoven*	Ricardo Enriquez Miranda
Brian Dean	Malcolm Orme	Sam Lam
Sabine Mitter	Irene Yong	
Michele Chew	Yeonjoo Cho	
Arijit Sengupta	Jimmy Lim Chee Meng	
Gao Chun Ping	Stephen D White	
Andreas Eckmanns	Paul Cooper	
Rob Kool*	Per Jonasson	
	Sunil Nair Saseedharan	
	Lee Boon Woei	
	Vincent Low	

* Rapporteur

Participants for parallel discussions on Opportunities

City and District Level – Policy & Market Implementation/Technology Needs and Solutions Facilitator: Sekhar Kondepudi & Veronika Shabunko Secretariat: Ng Shi Yu	**Building Level – Technology Needs and Solutions** Facilitator: Lee Poh Seng Secretariat: Roy Sim	**Building Level – Policy & Market Implementation** Facilitator: Lu Yujie Secretariat: Goh Xin Ying
Sabine Mitter	Toshihiro Nonaka	Brian Dean
Paul Ruyssevelt	Jimmy Lim Chee Meng	Joelle Chan
Andreas Eckmanns	Malcolm Orme	Arijit Sengupta
Michele Chew	Tjerk Reijenga	Tobias Gesch
Yeonjoo Cho	Marco Perino	Yao Meng
Gudrun Maass	Per Jonasson	Stephan Renz
Rob Kool	Pierre Jaboyedoff	Halime Paksoy
Ricardo Enriquez Miranda	Sameer Maithel	Stanford Harrison*
Teun Bokhoven	Irene Yong	
Sumedha Malaviya	Yuzhen Peng	
Mark Spurr*	Lee Boon Woei	
Hsieh Shan-Shan	Sam Lam	
	Lukas Lienhard	
	Poul E Kristensen	
	Paul Cooper	

	Ken Guthrie	
	Wong Nyuk Hien	
	Francois Garde	
	Deo Prasad	
	Stephen D White	
	Karl Wagner	
	Bharath Seshadri	
	Tham Kwok Wai*	
	Tan Tian Chong	

* Rapporteur

Participants for parallel discussions on R&D Priorities

Building Envelope and Occupant Behaviour Facilitator: Veronika Shabunko Secretariat Support: Ryan Toh / Majid Sapar	**City and District Scale** Facilitator: Sekhar Klinondepudi Secretariat Support: Ng Shi Yu	**Building HVAC and Systems** Facilitator: Lee Poh Seng Secretariat Support: Roy Sim / Noel Chin	**Grid and Storage Interaction, Renewable Integration** Facilitator: Stephen Tay* Secretariat Support: Goh Xin Ying
Marco Perino	Ho Hiang Kwee*	Sumedha Malaviya	Jimmy Lim Chee Meng
Brian Dean	Per Jonasson	Yeonjoo Cho	Teun Bokhoven
Francois Garde	Sabine Mitter	Stephen D White	Irene Yong
Rob Kool	Gudrun Maass	Bharath Seshadri	Michele Chew
Riccardo Enriques Miranda*	Halime Paksoy	Stephan Renz	Paul Ruyssevelt
Pierre Jaboyedoff	Andreas Eckmanns	Paul Cooper	Sumedha Malaviya
Malcolm Orme	Ken Guthrie	Yao Meng	
Tjerk Reijenga	Mark Spurr	Toshihiro Nonaka	
Stanford Harrison	Jimeno Fonseca	James Jian	
Sameer Maithel		Tay Yu Chan Zelia	
Deo Prasad		Lee Boon Woei	
Arijit Sengupta		Sam Lam	
		Tham Kwok Wai*	
		Karl Wagner	

* Rapporteur

7.5 Appendix 5 – List of Building Priorities

Based on the findings in the Future Buildings Forum Think Tank Workshop 2017, the potential R&D topics were collated as follows.

Major category	**Priority categories**	**Priorities within category**
Technologies	Cooling	Heat pumps Radiant and natural convectional cooling Passive displacement ventilation Personalized AC Ventilative cooling Hybrid cooling AC to suit the hot humid tropical climate. Adaptability of the coils for optimum performance
	Dehumidification	Desiccant Low energy dehumidification Decouple the latent cooling and sensible cooling
	Energy storage	Thermal energy storage Non-atmospheric heat sinks and sources Storage as an intermediary Alternative battery technologies Include energy storage in models / simulations / scenarios
	Lighting, appliances and plug loads	LED Management of plug loads
	Controls and sensors	Building energy management systems (BEMS) Building-level integration Optimal equipment loading Occupant and operator control Continuous monitoring Smart systems and predictive controls with artificial intelligence (AI) Predictive maintenance and optimization
Urban and city issues	Urban and city issues	Energy renovations and retrofit Urban microclimates Energy optimisation through urban form District energy solutions Intelligence that links buildings, energy grids and transport systems Decentralised renewable energy, better water, waste and air quality management Prepare for major disruptions in transport modes and technologies Thermal comfort as service
Materials	Building materials	Building envelope Thermal mass Embodied energy and greenhouse gas emissions
Multiple Benefits	Evidence of energy and non-energy benefits	
	Health and well-being	

Major category	**Priority categories**	**Priorities within category**
	Thermal comfort	Design / passive design Technology impacts (including insect screens affect the efficiency of ventilation through windows) Occupant thermal comfort guidelines (Occupant type impact on energy and occupant behaviour impact on energy) Behavioural changes Physiological studies Adaptive thermal comfort Occupancy modelling
	Noise pollution	
	Macro-economic impacts	
	Convenience / usability	
Quality	Quality	Installation and maintenance commissioning Guidelines and "how to" documents Training
Sustainable and resilient	Sustainable and resilient	Good design / passive design Technology and buildings designed to be reliable, adaptable / tolerant, reusable Sustainable and regenerative approaches (including biomimicry and integration of greenery) Long lifespan of the building
Investment	Investment	Walk the talk Readiness for finance Subsidies and financing
Market transformation	Technology designed to be:	Standardized Easily replicated Plug and play / reduce complexity Versatile
	Bulk purchasing	
	Supply chain	Technologies availability
Evaluation	Evaluation	Evidence of energy and non-energy benefits Understand the benefits Evidence-based policies/decisions Over the lifecycle of a building
Data	Data	Availability of data Data for policy making Big data AI and data analytics
Planning	Energy supply sector and the building sector	
	Full cost of energy including externalities	
	Roadmaps	Design, planning and policy
	Guidelines	Avoiding inappropriate technology / design habits Development and standardisation of guidelines

Major category	Priority categories	Priorities within category
Exergy	Exergy	Integration of hot water, waste heat into the heating and cooling systems Utilization of energy source from waste and excess heat Utilization of waste condensate
Energy efficiency and renewable energy integration	Green corridors	Renewable energy to microgrids / technologies / DC appliances
	Net zero energy buildings	
	Solar technologies	Use solar energy for air conditioning Absorption chillers with solar collectors Combined solar PV / thermal systems
Participation	Participation from countries in the tropics in the R&D work	Low carbon community (cities) in tropics

7.6 Appendix 6 – Presentations

The presentations can be found online at: www.iea-ebc.org/strategy/future-buildings-forum.

www.iea-ebc.org