MISSION INNOVATION

DEPARTMENT OF SCIENCE & TECHNOLOGY
Ministry of Science and Technology
Government of India

Mission Innovation IC7

Deep dive workshop on “Low carbon, Affordable Heating and Cooling of Buildings”

Focus Area: Thermal Comfort

New Delhi, 6th November 2019

Workshop Summary Report

Organised by

European Commission | India | United Arab Emirates | United Kingdom

Indian Institute of Technology Delhi, India

Indian Institute of Technology Roorkee, India

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Glossary of terms

BEE	: Bureau of Energy Efficiency, India
BEIS	: Department for Business, Energy & Industrial Strategy , UK
BIS	: Bureau of Indian Standards
DST	: Department of Science and Technology
GCP	: Global Cooling Prize
IC	: Innovation Challenge
ICAP	: India Cooling Action Plan
IoT	: Internet of things
ISHRAE	: Indian Society of Heating Refrigeration and Air Conditioning Engineers
MI	: Mission Innovation
MoEFCC	: Ministry of Environment, Forest and Climate Change, India
PA	: Priority Area

1. Introduction

Mission innovation (MI) is a global initiative of 24 countries and the European Commission to accelerate global clean energy innovation. As part of the initiative, participating countries have committed to double their Governments' investment in clean energy research and development (R&D). MI countries have established eight Innovation Challenges (ICs) as the foundation for accelerating clean energy innovation while also providing opportunities for new collaboration that build on multi-lateral research and development efforts. MI identified Innovation Challenge 7 (IC7) "Affordable Heating and Cooling of Buildings" as one of the eight innovation challenges.

The objective of the IC7 is to make low carbon heating and cooling affordable for everyone. The IC is co-led by the UK, UAE and European Commission and has membership from Australia, Austria, Brazil, Canada, China, Denmark, Finland, France, Germany, India, Italy, Mexico, Norway, Netherlands, Republic of Korea, Saudi Arabia, Sweden and USA. India is strongly committed and engaged with IC7 and leads one of the Priority Areas (PA) - Thermal Comfort. To support this PA, India's Department of Science and Technology (DST) hosted a deep dive IC7 workshop focussed on the Thermal Comfort Priority Area on the 6th Nov 2019 in New Delhi. This report provides a summary of the proceedings and suggested next steps.

2. Focus area of the Workshop: Thermal comfort

The workshop was aimed to facilitate face-to-face meeting, technical interaction and networking in IC7 PAs with specific focus on Thermal Comfort. The workshop took cognizance of the synergies between Thermal Comfort, Predictive Maintenance & Optimization and Building Integration.

2.1 Aim and objectives of the workshop

The workshop intended to identify key opportunities for research and innovation in the thermal comfort PA that will enable low carbon affordable heating and cooling of buildings. The specific objectives were to:

1. Explore research innovation opportunities in three topics with impact namely Thermal Physiology, Systems and Technologies, and Operational Controls.
2. Identify common areas of collaboration, individuals/ organisations interested in working together and agree some next steps

2.2 Agenda and Speakers

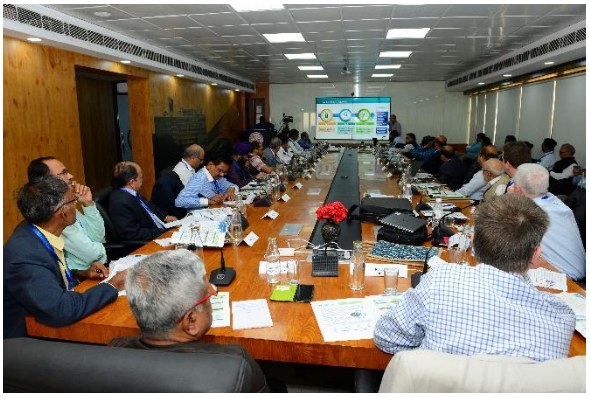
- Welcome address – J.B.V. Reddy, Department of Science and Technology, India.
- Overview of MI and progress in IC7 – Jon Saltmarsh, BEIS, UK - Representing IC7 Co-Leads
- Background and objectives – S C Mullick, Indian Institute of Technology Delhi and S S Murthy, Indian Institute of Science Bangalore, India
- Technical Session - Overview of the Thermal Comfort Priority Area – Co-chaired by Sukumar Devotta (Former Director, NEERI, Nagpur) and Jon Saltmarsh, IC7 Co-Lead
- Thematic Session I: Systems and Technologies – Co-chaired by Pietro Menna, EC, IC7 Co-Lead and Sanjeev Jain, Indian Institute of Technology Delhi
- Thematic Session II: Thermal Physiology – Co-chaired by Graeme Maidment, IC7 Co-Lead and M P Maiya, Indian Institute of Technology Madras
- Thematic Session III: Thermal Physiology – Co-chaired by Piero De-Bonis, EC, IC7 Co-Lead and Vishal Garg, Indian Institute of Information Technology Hyderabad.
- Valedictory address – Abhay Bakre, Director General, BEE
- Recommended action points and Roadmap – Co-chairs – IC7
- Closing Address – Sanjay Bajpai, DST

Five IC7 Co-Leads attended the workshop including Jon Saltmarsh and Graeme Maidment from the UK and Pietro Menna and Piero De Bonis from the European Commission. Amal Hamadeh from the UAE connected virtually. In total, 45 participants in addition to the organisers attended the workshop. This included 10 participants from government bodies, 16 from academia and 19 from industry – all attended the workshop physically. Professor Sukumar Natarajan from the University of Bath and Chandra Sekhar from the National University of Singapore attended virtually.

3. Summary of Workshop

3.1 Overview of MI and IC7.

The workshop started with welcome address by JBV Reddy. Jon Saltmarsh, highlighted the work in six priority areas and updated on various funding announcements on the comfort climate box, predictive maintenance and optimisation, sorption heat pumps, thermal energy storage (TES) as well as about the Global cooling prize (GCP). Major activities in thermal comfort and alternative heat sinks were reported as planned for 2020 onwards. Dr N P Padhy presented the possible synergies between IC1, IC6, and IC7. IC1 intends to enable future grids that are powered by affordable, reliable, decentralized renewable electricity systems. IC6 intends to accelerate the exploration, discovery and use of new high-performance, low-cost clean energy materials. Dr. Padhy highlighted the complementary priority areas in the three ICs such as demand response and storage integration and the potential for collaboration.



3.2 Overview of the Thermal Comfort Priority Area

This technical session started with an overview of DST's IC7 initiatives presented by Dr E Rajasekar. Initiatives included a National workshop, various liaision programs conducted to promote industry and academia collaboration. A status report on thermal comfort was drafted and was used to formulate three focus topics with impact namely Thermal Physiology, Systems and Technologies, and Operational Controls.

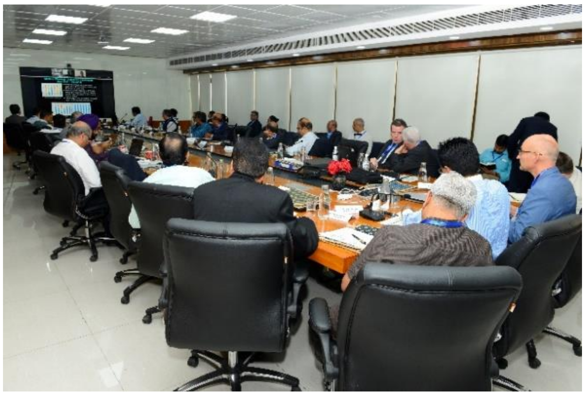
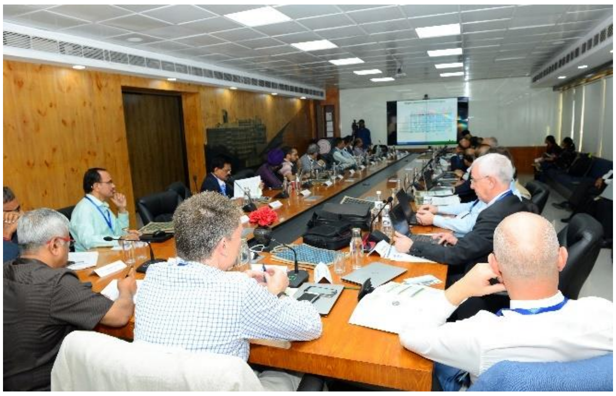
Dr Rajasekar highlighted the opportunity to reduce emissions through innovations and better understanding of the science of thermal comfort. Innovation in thermal comfort has the potential increase in energy efficiency of buildings and to save 20-27% annual cooling energy and 25-34% annual heating energy in fully HVAC controlled buildings and up to 70% annual energy in mixed-mode buildings depending on the climate and building character. In particular, there is opportunity to dovetail the Thermal Comfort PA with other PAs of IC 7. He also spoke about the thrust on technology development and prototyping for improved Thermal Comfort.

Graeme Maidment emphasized the challenges and opportunities to link the intermittency and volatility of renewable energy resources to the thermal comfort. This links well with predictive maintenance and control and the use/ availability of big data. Reducing demand for heating and cooling could result from raising set point temperatures in summer, which would enable use of more efficient systems and open up opportunities for alternative heat sinks/ sources. Innovation in personal climate control systems would reduce the demand for heating and cooling by only conditioning the occupied areas.

Dr Gopalakrishnan, CSIR-CBRI briefed on recent achievements on affordable heating and cooling of buildings in India and also the future perspectives of research in CBRI. Marcus Knight, MoEFCC discussed the India Cooling Action Plan (ICAP). The cooling industry is mainly based on refrigeration based cooling systems, which is about 80 per cent of the cooling installed capacity and is expected to increase to 87 per cent in the next three years. The main benefits of the action plan are to improve farmer's income as well as supporting the "Make in India" programme. The ICAP also aims to reduce cooling demand by 20 to 25% and energy use by 25 to 40% by 2037. Dr Sanjay Pant, BIS gave an overview of building energy efficiency initiatives, the sustainability part of the National Building Code and revisions of bye laws towards lower energy use.

3.3 Thematic Session I: Systems and Technologies

The session started with Indian academic perspective by Dr MV Rane where he emphasised the need for a whole systems' approach for optimising the use of all systems in buildings including - Power Generation, Heating and Cooling, Energy Storage, Potable Water Generation and Water Recycling. Session speakers detailed the recent advances in low energy heating and cooling systems like efficient rotary, invertor compressors, Variable Frequency Drive units, IoT based system control and effective design using advanced tools like Computational Fluid Dynamics. Dr Kalpesh from A.T.E enterprises discussed the need for mixed mode conditioning and implementation of indirect/direct evaporative cooling of buildings. Further Amal Hamadeh, UAE Co-Lead gave progress updated on IC7 activities in UAE where work related to solar cooling and non-atmospheric heat sinks happen. The session stimulated a lot of discussion on research gaps and needs.

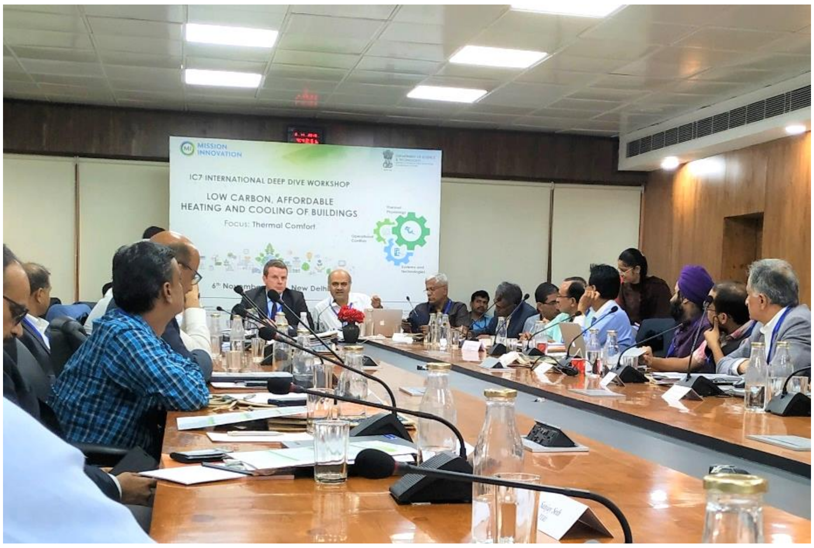
Some of the key technical challenges and enablers identified are:

- Need to approach overall system efficiency instead of individual equipment and a whole systems' approach to buildings with integrated operation.
- Integration of heat/enthalpy recovery in the systems such as alternative heat sinks and sources.
- System load reduction by using Green Building design techniques. Introduction of mixed mode operation in building guidelines.
- Need for integrated heating and cooling system.

- Source and demand integration in a generalized and customized way.
- Innovation in personal climate control systems would reduce the demand for heating and cooling by only conditioning the occupied areas. Personalized control for various climatic zones to reduce the HVAC load instead of conditioning the whole occupant space.
- Reducing demand for heating and cooling could result from raising set point temperatures in summer, which would enable use of more efficient systems and open up opportunities for alternative heat sinks/ sources.
- In the present scenario, increasing efficiency is leading to high initial costs, which for Indian users plays an important role in the market. The systems should be value engineered which will lead to a system which will not compromise energy efficiency, affordability and will satisfy user requirements.

3.4 Thematic Session II: Thermal Physiology

The session started with a brief about Thermal comfort and Indoor Air quality by Dr Chandra Shekar, NUS who discussed about human centric building design, importance of envelope/ façade design, ventilation and air quality acceptability. Dr Sukumar Natarajan, University of Bath discussed about research approaches in thermal comfort. Tropical and sub-tropical climates imply significant increase in cooling energy demand as the global built up area will increase by 270 million m^2 by 2050. A new humidity adjusted adaptive comfort model shows higher limits of indoor temperature with a decrease in discomfort hours. Dr R Saravanan, ISHRAE gave a brief summary of the role of thermal comfort in the HVAC industry and the need to give Mean Radiant Temperature based control settings to suit seasonal climatic changes. Rajan Rawal, CEPT, Ahmedabad discussed various studies on thermal comfort, adaptive models and assessment low carbon cooling, Indian clothing values and air velocity studies. Jiten, JP consultants presented on the design of passive solar building design to achieve thermal comfort with least mechanical conditioning. Sanjay Seth, TERI discussed on thermal comfort and building energy efficiency.



Some of the key challenges and opportunities are

- Need to do research on physiological studies for thermal comfort in different climatic zones of India and further afield.
- Better understanding of the impact of transient thermal comfort conditions on the potential for flexible heating and cooling systems will increase the use of intermittent renewables. This links well with predictive maintenance and control and the use/ availability of big data.
- Adaptive thermal comfort needs investigation and could result in reduced demand for heating & cooling as described in the previous section.
- Importance of ventilation and air acceptability has to be duly considered. There is a need to augment air conditioning with air movement for better comfort. Importance of envelope/ façade design on thermal comfort.

- Need for reliable localized weather data and linking this to localised adaptive thermal comfort.
- Introduction of proxy variables for comfort instead of just temperature set point and study occupants' comfort preferences.
- Need for multidisciplinary approach building design for comfort and promote mix-mode buildings.
- Need for behaviour responsive thermal comfort controls
- New Standards are essential which provide information to consumer/ market.

3.5 Thematic Session-III: Operational Controls

The session discussed the operational control of HVAC systems, sensing techniques and data analytics in operation. The session started with recent advances in HVAC operational controls by Dr P Ravichandran, Danfoss who spoke about the importance of energy systems towards decarbonisation, integration of heating and cooling with heat recovery and decentralized heat pumps. He pointed out that while energy demand is increasing, the resources are still the same. Dr R Malur, TCE stressed the importance of Eco-first sustainable architecture integrating active and passive design strategies for thermal comfort. He suggested to consider the fact that ⅔ population will be in cities while designing operation and control techniques. Further, Amarjeet Singh from Zenatix discussed recent advances in building performance sensing, IoT enabled BMS and the need to focus on local control, passive sensing and connected solutions. Currently, less than 5% of buildings are BMS enabled. Arjun, from Smart Joules discussed centralised cooling systems focusing on hospital sector in India and the case study data showed that only few Variable Frequency Drives are actually modulating. He stated that operational control of chillers can have a payback period of just 3 months. Dr Balasubramanian, IITR explained about big data and its applications in smart buildings and need to use deep learning techniques instead of conventional algorithms. Dr A K Agarwal and Dr D P Bhatt stressed the need to improve refrigerants and develop criteria for selecting refrigerants based on the use. Dr Sukumar Mishra, IITD discussed that Artificial Intelligence and Machine Learning will help to control transient power flows to enable net zero buildings, which have different electricity demands. Following the presentations, a facilitated group discussion took place with some questions to the audience related to opinions about operational controls.

The key technical challenges and enablers identified in the discussion are:

- Need to integrate data analytics in operation and predictive maintenance.
- IoT based sensing and use of advanced techniques like deep learning to operate system has a good potential.
- Need for original equipment manufacturer connected solutions and "Cooling as A Service" business models. Centralised connectivity of different systems through a common platform is

needed. Allied industries need to be interlinked for smooth process through single unified standard.

- Decentralization of heat pumps and chillers for small and large thermal networks is a potential area of development.
- Need to build knowledge of end users such as facility management teams for effective operation and control for efficient implementation.
- Need to model predictive control of HVAC based on Artificial Intelligence and to standardize sensors for data reliability.
- New non-invasive ways of sensing thermal comfort through imaging need to be explored. Control based on tracking thermal and visual responses of occupants has a good potential. Control algorithms to collectively arrive at set point parameters based on the occupant's thermal behaviour need to be work out.
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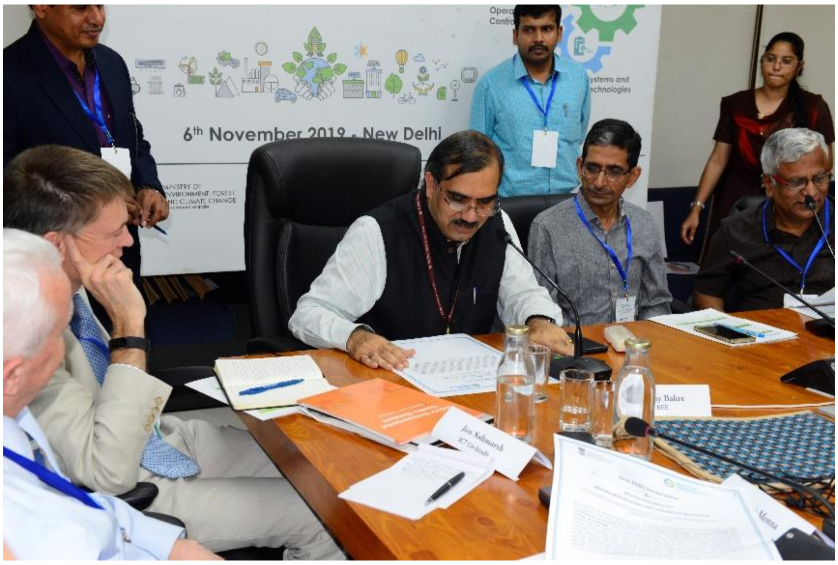
3.6. Concluding session

Dr. Abhay Bakre, DG, Bureau of Energy Efficiency, in his valedictory address noted that IC7 is covering the high impact areas and is potentially one of the important ICs among all. He appreciated that the workshop has given a platform linking all the stakeholders. Solutions will be implemented in India and other countries based on the learnings from IC7. He added that a key aspect which needs to remembered is "how to make low carbon, affordable heating and cooling of buildings without comprising the aspirations of the consumers? That's a challenging role for policy makers."



Dr Sanjay Bajpai, DST, in his closing address credited the Mission Innovation platform which has enabled this collaboration. The Global Cooling Prize created significant interest amongst the scientists and it's likely that the India Cooling Action Plan will follow suit. DST's initiatives will nurture research and development and reinforce the goals of Mission Innovation. He concluded by saying "we will develop a strong ecosystem of Industry, R&D, scientists, academia, policymakers to develop holistic solutions".

The workshop concluded with the New Delhi declaration (content appended as annexure I). All delegates agreed that they will strive to stimulate research, technology and innovations to enhance thermal comfort and well-being in buildings and deduce methods to provide affordable comfort for all at minimum energy and emissions.

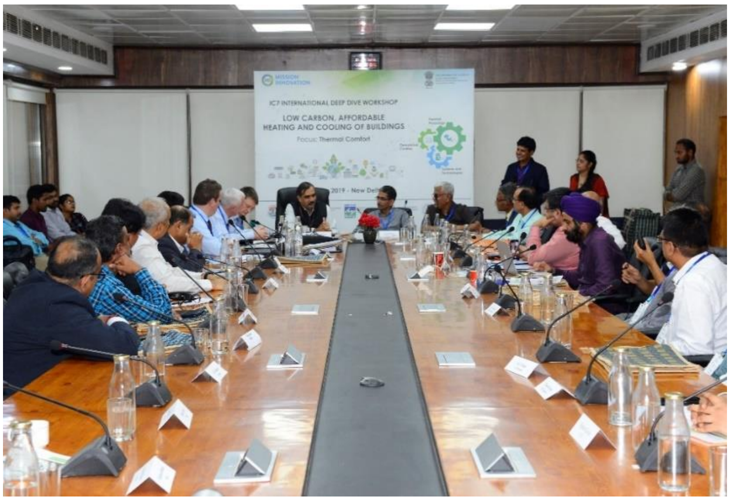
4. Next steps

The following key points emerged out of the workshop

i. There needs to be research and development on thermal physiology considering interdisciplinary applications to building design, HVAC system design and operational controls for different climate zones. Research on aspects such as relation between thermal physiology, occupant behaviour and comfort preferences could hold the key to better optimization of design and building operations. There is significant potential for revisiting the current thermal comfort standards. Such work can facilitate the development of comfort based controls in place of the current day temperature based controls. This will have a positive impact on energy efficiency and indoor environmental quality.

ii. There needs to be studies on ventilation (including natural ventilation) and thermal comfort studies with due considerations for air quality. Free cooling has a good potential in countries like India if air quality can be resolved. Need for research in mixed mode system and operation. Jon Saltmarsh emphasised on what India can do for MI in the priority areas and other Innovation challenges and proposed to connect key people in those challenges. There is a critical need for value engineering the energy efficient systems and technologies, which will help main-streaming such technologies despite higher initial costs. This will also help industry to consider “cooling as a service” business models.

iii. Data is becoming the prime-mover of building operations. There is an immense potential to develop standard frameworks for data capture from different building types. This would include standardisation of IoT based sensing techniques for different building types, development of standard protocols for data collection and encouraging open-source data repositories on building as well as system performance. Research and development on data driven controls, predictive maintenance are critical in order to address tomorrow’s building needs. This can encompass use of artificial intelligence development of connected systems and sensory controls.



To facilitative the above research and development activities, DST will establish three work groups one each on Thermal Physiology, Systems and Technologies and Operational Controls. DST will develop a questionnaire to will map the current research in the respective areas, market status, international status and potential for future research. Based on this a research project/program with research sprints will be developed in coordination with the IC7 leads/co-leads.

Annexure – I: New Delhi Declaration

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MISSION INNOVATION
accelerating the clean energy revolution

New Delhi Declaration

Mission Innovation IC7

AFFORDABLE HEATING AND COOLING OF BUILDINGS

FOSTERING COOPERATION FOR RESEARCH AND DEVELOPMENT IN THERMAL COMFORT

We, fraternity of Mission Innovation IC7 "Affordable Heating and Cooling of Buildings", having participated in the deep dive workshop on 6th November, 2019 at New Delhi, **reaffirm our commitment to intensify our collaboration to realize low carbon affordable heating and cooling of buildings.** We will strive to stimulate research, technology and innovations to enhance thermal comfort and well-being in buildings and deduce methods to provide affordable comfort for all at minimum energy and emissions. We will nurture cross-innovations with the objectives to develop technological solutions that can lead to comfortable, sustainable and energy efficient buildings. We will resolve to facilitate thermal comfort integration with building systems. We also resolve to explore avenues for a greater and sustained support for national, bilateral and multilateral cooperation including engagement with international agencies to foster the objectives of this challenge. We resolve to identify opportunities for greater private sector engagement. Together, we resolve to contribute to the larger Mission Innovation Goal of accelerating affordable and sustainable clean energy innovation.