FURTHERING SUSTAINABLE AND SMART SPACE COOLING SOLUTIONS

PART 1: A SCOPING REPORT FOR DEVELOPING A WINDOWS ENERGY LABELLING PROGRAMME IN INDIA

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PART 2: A MARKET ASSESSMENT OF LOW ENERGY COOLING TECHNOLOGIES

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EXECUTIVE SUMMARY

PART 1: A SCOPING REPORT FOR DEVELOPING A WINDOWS ENERGY LABELLING PROGRAMME IN INDIA

With most of India's air-conditioner stock yet to come, now is the critical window of opportunity to build in interventions that will have a meaningful impact on future energy consumption and emissions. These savings can be realized through a combination of interventions of which the building envelope is critical. The India Cooling Action Plan recommends efficient or 'passive' building designs which can reduce the overall heat-gain in a building thereby significantly decreasing the cooling energy demand as the need for an AC system to reject this heat from the conditioned space reduces. In this regard, windows become an important area of exploration, to manage the heat gain and thus optimize the cooling needs of a building.

The energy-efficiency of a window system depends on its thermal and light transmittance abilities, which are mainly manifest in the following parameters:

- Solar Heat Gain Coefficient (SHGC): This measures how well a product can resist unwanted solar heat gain, which is especially important during the summer cooling season.
- U-value: This measures how well a product can keep conductive heat from entering the room.
- Visible Light Transmittance (VLT): This measures how well a product is designed to effectively light your home with daylight.

The ECBC 2017 lays out compliance requirements for vertical fenestrations in terms of SHGC and U-factor. The draft ECBC-R Part-1 focuses on minimising heat transfer through the building envelope to achieve comfortable indoors. It indicates that the maximum Residential Envelope Transmittance Value (RETV) for building envelope for four climate zones i.e. Composite, Hot and dry, Warm and humid, and Temperate. Further, the Code requires compliance of VLT of non-opaque building envelope components with the minimum VLT values. NBC 2016 Volume 2, Part 11 – Approach to Sustainability, Section 8 – Envelope Optimisation provides guidance on building envelope including fenestration. The Code promotes minimising heat transfer through the fenestration and provides specifications for window size and placement, glazing, and frame.

There are 3 facilities to assess the energy performance of the windows in India i.e. IITM in Chennai, CARBSE at CEPT University in Ahmedabad and CSIR-CGCRI in Kolkata. These facilities can typically handle aluminium and uPVC windows of various sizes and receive orders for up to 50 orders annually per facility. They employ engineers and semi-skilled labourers; they are trained internally. Once an enquiry is received, including the test parameters and drawings), the method the statement is prepared the testing is proceeded with.

With significant growth in the real estate sector on the horizon, it is important to roll out a window labelling programme for India. Window labelling can help developers and end users choose the right windows for minimising the ingress of heat into buildings, thereby reducing the cooling energy consumption needed for maintaining satisfactory levels of indoor thermal comfort. Beyond energy-related benefits, programmes like these can lend credibility to manufacturers, increase their business and add value to customers. Moreover, there is better awareness in builders and consumers about using energy-efficient windows. In this regard, it would be useful to review existing windows labelling programmes internationally. Table A briefly presents the salient features of some of these programmes:

Table A: Salient features of the NFRC, the AFRC and the BFRC

	Type	Parameters considered	Simulation testing	Physical testing	Inspection agency capacity
NFRC	Direct value reporting (no rating/ranking)	Mandatory: U, SHGC, VLT Voluntary: Air leakage, condensation resistance	Yes	Yes	Yes
AFRC	• Star labelling for heating and cooling performance • Indicative per cent reduction in heating and cooling needs • Direct value reporting	U value, SHGC, VLT, fabric fading transmittance, and air filtration	Yes	No	Unclear
BFRC	• 7-point rainbow scale (A++ (best) to E (worst)) • BFRC energy index	BFRC energy index, which is a function of U value, SHGC, air leakage	Yes	No	Yes

Delineated below is a set of high-level recommendations to create an ecosystem to foster a windows energy labelling programme in India:

<u>Market transformation mechanisms</u>

- Government policies related to Smart Cities should advocate the inclusion of energy efficient windows and glazing. We recommend developing sustainably cooled 'Demonstration Projects' in a few sites, piloting innovative window solutions. The calculated energy saving outcomes in these demonstration projects should be highlighted through Government Technology Alerts to create awareness and establish the credibility of HP glazing in enhancing thermal comfort and reducing the building's cooling needs.
- Make ECBC implementation mandatory in all states. Provide governance to ensure strict compliance with all mandatory codes. Over time, develop variants of ECBC or simplified energy efficiency codes/ guidelines to cover smaller commercial buildings. ECBC 2017 prescribes WWR, U-values and SHGC – our analysis shows that even with base ECBC 2017 compliance half of the total energy savings potential can be realised.
- Establish policies to create state-level financial facilities for a low-cost/preferential line of credit to real estate projects with a demonstrably energy-efficient building envelope, including energy-efficient windows.
- Promote the concept of 'Green Leasing' in commercial spaces: the idea is that the building owners could charge a premium rent for an energy efficient space, and the tenant would benefit from enhanced occupant comfort and operational savings achieved through lower energy bills.
- Introduce sustainable rating of architects/architecture firms based on a suitable building performance or energy efficiency quotient (e.g. the average EPI of operational project portfolio). Mandating minimum eligibility criteria for practising architects in terms of these ratings will help ensure a constant push towards the embodiment of energy efficiency and sustainability features in their projects, including energy efficient windows glazing.

- Create consumer awareness through campaigns, demonstration projects, infomercials, and stakeholders across the construction supply-chain that focus on promoting and cultivating energy-conserving behaviour in space cooling; educate customers to make informed product choices based on operational savings, rather than the first cost alone.

Capacity building mechanisms

- Capacity ramping up in terms of testing, both physical testing and simulation, infrastructure and training and awareness to be scaled up
- Introduce sustainable rating of architects/architecture firms based on a suitable building performance or energy efficiency quotient (e.g. the average EPI of operational project portfolio). Mandating minimum eligibility criteria for practising architects in terms of these ratings will help ensure a constant push towards the embodiment of energy efficiency and sustainability features in their projects, including energy efficient windows glazing.
- Undertake capacity building, training and awareness exercises including setting up a centre of excellence for HP windows and glazing. Facilitate up-gradation of existing curricula across relevant streams/ branches/fields of study to include sustainable cooling techniques.
- Create a robust knowledge-sharing and collaborative platform to bring together stakeholders across the window manufacturing and installation supply-chain from both the organised and unorganised sectors.

PART 2: A MARKET ASSESSMENT OF LOW ENERGY COOLING TECHNOLOGIES

In this Part, low energy cooling technologies refer to unconventional cooling technologies that are not as energy intensive as vapour compression cooling. These can be used as either standalone cooling systems or in conjunction with the conventional air-conditioning. These technologies offer advantages of reduced cost or complexity, increased reliability, peak demand reduction, energy savings and GHG reduction. These technologies have been applied at sizeable scales in commercial buildings in India and are known to provide other non-energy benefits, which include improved indoor air quality, noise reduction and integration with Internet of Things (IoT) for better control and monitoring.

The India Cooling Action Plan (2019) identifies promoting the development and commercialization of technology pathways, especially low-energy cooling technologies, which would reduce the energy footprint of active cooling as a priority area. Through the right combination of policy and market drivers, the private sector must be enabled to lead the technology development through innovation and R&D. The technology pathways must include, inter alia, the evolution of not-in-kind technologies for scaled-up adoption.

An extensive manufacturers' survey low energy cooling technologies was carried out. The survey aimed to make a market assessment of low energy cooling technologies including information on:

- Description of the technology
- The capacity of the available systems
- Effectiveness in providing thermal comfort
- Cooling efficiency and energy saving potential
- Applicability for Indian conditions, i.e. climate zones, type of buildings
- Current market conditions in India for standalone products – market size, product specs, price, penetration, customer type – residential and commercial
- Discussion on the cost-effectiveness of incorporating low energy cooling technologies, including
- incremental costs and potential pay-back periods

A consolidated form of the relevant responses received has been presented in Table B.

Table B: A brief summary of the manufacturers' survey

	Vapour Absorption Machine (VAM)	Radiant cooling	Indirect-Direct Evaporative Cooling (IDEC)	Direct Structure Cooling (DSC)
Suitable building types	Offices, hotels, hospitals, institutions, retail, and industrial cooling and refrigeration	Offices, hotels, institutions, retail, in some healthcare facilities, and other commercial spaces like warehouses, industrial spaces, libraries, and airports	Residential buildings, offices, hotels, institutions, retail, in some healthcare facilities, and industrial spaces	Offices, hotels, institutions, retail, healthcare facilities, and industrial spaces
Temperature profile	5-30°C	22-26°C	4-5°C lower temperature wrt evaporative cooling	DSC can drastically reduce the diurnal range of temperature within the structure
RH profile	30%-60% RH	30%-60% RH	60% lower RH wrt evaporative cooling	
Climate/season feasibility	Year-round application in all the 5 climate zones of India	Dry season application in all the 5 climate zones of India	Dray season application in composite, hot and dry, and temperate climate zones	Year-round application in all the 5 climate zones of India
Main pre-requisite	An unending source of low-grade heat or waste heat	-	Water	
Typical set-point	7°C chilled water temperature	25°C	28(+/-2)°C	
System break-down causes	Vacuum break, poor water quality and corrosion	Air gaps and pump/valve failure	Poor water quality, improper air filters and negligent maintenance	

Energy performance	COP: 0.8-1.9 EPI: 100 kWh/m^2/year	30%-50% less energy/area as compared to VC	IDEC can deliver up to 5 ISEER; it consumes around ½ kWh per 100 CFM	
Payback period	1-4 years	1-5 years	1-2 years	
Installed capacity (from 2007-2017 in terms of replacing TR of conventional AC)	0.7 million TR	18,000 TR	0.1 million TR	4,600 TR

The survey identified the following market barriers to their mainstreaming:

- Lack of awareness among consumers
- Limited market players
- Higher upfront cost compared to conventional air-conditioning (sometimes)
- Limited technology know-how and the unwillingness of HVAC consultants to experiment with new cooling solutions
- Limited government support

TABLE OF CONTENT

PART 1

A SCOPING REPORT FOR DEVELOPING A WINDOWS ENERGY LABELLING PROGRAMME IN INDIA

1 INTRODUCTION

With most of India's air-conditioner stock yet to come, now is the critical window of opportunity to build in interventions that will have a meaningful impact on future energy consumption and emissions. These savings can be realized through a combination of interventions of which the building envelope is critical. Buildings can be intrinsically energy-thrifty if they are well designed and adhere to building energy codes. 'Lean' measures can reduce heat gains, thereby reducing the cooling demand throughout the operational life of the building. In this regard, windows become an important area of exploration, to manage the heat gain and thus optimize the cooling needs of a building. Heat gain in buildings is primarily due to conduction, convection and radiation through roofs, walls, windows and doors. Windows are directly linked with these three modes of heat transfer and can form a key aspect of designing buildings. The India Cooling Action Plan recommends efficient or 'passive' building designs which can reduce the overall heat-gain in a building thereby significantly decreasing the cooling energy demand as the need for an AC system to reject this heat from the conditioned space reduces [1].

2 CRITERIA FOR ENERGY-EFFICIENT WINDOWS

2.1 Thermal transmittance

Solar Heat Gain Coefficient (SHGC) measures how well a product can resist unwanted solar heat gain, which is especially important during the summer cooling season. SHGC indicates the percentage of solar heat energy (direct radiation) that makes its way through the fenestration product under standard summer conditions. A lower value indicates less heat entering the building and thus a more energy efficient home if used in a warm climate or east or west elevation. SHGC should be low in hot climates and high in cold climates. External shading devices can be used to keep out solar radiation.

U-value measures how well a product can keep (conductive or non-solar) heat from escaping from the inside of a room or entering the room. U-value is the measure of heat loss or gain due to differences in temperature/environmental conditions between the inside of the home and outside of the home. A lower U-value indicates better insulating performances and thus a more energy efficient home. U-value should be lower in both hot and cold climates.

Low-E, solar-control, Insulated Glass units (IGUs) and Double Glass Units (DGUs) are some glazing options to reduce the ingress of heat into the building. For energy efficiency, some window frames are designed with internal thermal breaks that reduce heat flow through the frame.

The sealing between the openings and the window frames and between the opening sashes of windows and fixed portions are important areas to be addressed as major heat loss happens from these areas due to air infiltration. Thus, ensuring continuity of each component serving its role in resisting infiltration such as a window assembly or a curtain wall is important.

2.2 Light transmittance

Visible Light Transmittance (VLT) measures how well a product is designed to effectively light your home with daylight. VLT is the fraction of light at a normal incidence that is transmitted through a fenestration product, giving natural light to the inside of a building. Dirt on glazing can reduce VLT appreciably - to ensure day-lighting levels are adequate, regular cleaning of the glass is important.

However, glare i.e. the excessive contract of illumination or excessive illumination in the field of view should be avoided. Glare can be reduced by the use of external shading devices like canopies, overhanging floors, or louvre systems and by the use of internal screens.

3 EXISTING GUIDELINES FOR ENERGY-EFFICIENT WINDOWS IN INDIA

3.1 Energy Conservation Building Code (ECBC) 2017 [2]

ECBC 2017 laid out compliance requirements for vertical fenestrations in terms of SHGC and U-factor as summarized in Table 1. The maximum allowable Window Wall Ratio (WWR) is 40%. The ECBC refers to ISO 15099 in the absence of appropriate national standards by the Bureau of Indian Standards (BIS). BIS has so far not developed a standard that specifies the detailed calculation procedures for determining the thermal and optical transmission properties (U-Value, SHGC, and VLT) of windows. International standards interpreted with regional or national characteristics including, but not limited to, accounting for local climatic variations have been referred by ECBC at other instances (such as for opaque construction) as well. ISO-15099 suggests that individual national standards will need to be more specific and in other cases, the ISO document gives users the choice of multiple options. ECBC clarifies these specific issues as they are to be implemented in India.

Table 1: Vertical fenestration assembly U-value and SHGC requirements for ECBC, ECBC+ and SuperECBC buildings

	Composite	Hot and dry	Warm and Humid	Temperate	Cold
	The values listed are in the following sequence ECBC/ECBC+/SuperECBC				
Maximum U-value ($W/m^2.K$)	3/2.2/2.2	3/2.2/2.2	3/2.2/2.2	3/3/3	3/1.8/1.8
Maximum SHGC Non-North	0.27/0.25/0.25	0.27/0.25/0.25	0.27/0.25/0.25	0.27/0.25/0.25	0.62/0.62/0.62

Maximum SHGC North for latitude ³ 15°N	0.5/0.5/0.5	0.5/0.5/0.5	0.5/0.5/0.5	0.5/0.5/0.5	0.62/0.62/0.62
Maximum SHGC North for latitude < 15°N	0.27/0.25/0.25	0.27/0.25/0.25	0.27/0.25/0.25	0.27/0.25/0.25	0.62/0.62/0.62

3.2 Energy Conservation Building Code - Residential (ECBC-R) (draft)

The draft ECBC-R Part-1 focuses on minimising heat transfer through the building envelope to achieve comfortable indoors. It indicates that the Residential Envelope Transmittance Value (RETV) (i.e. the net heat gain over the cooling period per unit area except for the roof) for building envelope for four climate zones i.e. Composite, Hot and dry, Warm and humid, and Temperate, shall comply with the maximum RETV of 15 W/sqm. Further, the Code requires compliance of VLT of non-opaque building envelope components with the minimum VLT values as given in Table 2.

Table 2: Minimum visible light transmittance (VLT) requirements

Window-to-wall ratio	Minimum VLT
WWR ≤ 20%	≥ 75%
20% < WWR ≤ 30%	≥ 50%
30% <WWR ≤ 35%	≥ 40%

3.3 National Building Code (NBC) 2016 [3]

NBC 2016 Volume 2, Part 11 – Approach to Sustainability, Section 8 – Envelope Optimisation provides guidance on building envelope including fenestration. The Code promotes minimising heat transfer through the fenestration and provides specifications for window size and placement, glazing, and frame. While selecting glazing, the code provides the following guidance: selecting between dual pane and single pane glazing, selecting spectrally selective glazing (to keep off infra-red and permit visible light), balancing between glare and light, trading off window size and glazing selection, dark or tinted glass and solar control, glazing as just one of the many options to reduce heat gain and discomfort, selection of frame for glazing and varying the selection and configuration of a glazed facade. Further, the Code recommends sealing some edges and corners to reduce heat ingress. While the guidance for energy-efficient glazing and frame is provided, it lacks supporting the provisions with numbers. The Code lists 3 compliance methods i.e. prescriptive, envelope trade-off and whole building performance in Part 11 - Annex B, C and D, respectively.

3.4 Others [4-7]

The Building Energy-Efficiency Project (BEEP) design guidelines for energy-efficient multi-storey residential buildings (composite, hot and dry, and warm and humid climate) highlights window properties such as single glazing or double glazing, VLT and U-value, amongst many other factors influencing the demand for cooling and thermal comfort in a residential unit. The guidelines promote window shading over double glazed units (DGUs).

The Model Building Bye-laws encourage provisions of ECBC guidelines and Model Energy Efficiency guidelines (NSMH Subreport by Bureau of Energy Efficiency) into the state respective building bye-laws. The Model Energy Efficiency guidelines refer to ECBC 2007 for fenestration U-factor and SHGC.
The review of the existing policy framework provides enough evidence that there is an emphasis on the use of HP glazing in the building sector. Minimising heat transfer by restricting to prescribe SHGC, U-value, VLT, single glazed unit (SGU) and DGU values/ranges are being practised in India building widely. While these parameters are discussed in more detail in energy codes, detailed inclusion and maintaining stringency of the high-performance glazing design parameters in building codes will reap high energy savings.

4 EXISTING TESTING INFRASTRUCTURE IN INDIA

There are 3 facilities to assess the energy performance of the windows in India i.e. IITM in Chennai, CARBSE at CEPT University in Ahmedabad and CSIR-CGCRI in Kolkata.

A brief questionnaire (Appendix A) was shared with these labs with the help of the Glazing Society of India (GSI). Given below is a consolidated form of the responses obtained:

These facilities can typically handle aluminium and uPVC windows of various sizes and receive orders for up to 50 orders annually per facility. They employ engineers and semi-skilled labourers; they are trained internally. Once an enquiry is received, including the test parameters and drawings), the method the statement is prepared the testing is proceeded with. Table 3 lists out some typical tests, testing standards and processing times for these facilities.

Table 3: Some typical tests, testing standards and processing times

	Testing standard	Processing time
Glass U-Factor	ISO 9050/ EN 410 / NFRC 300	7 days
Window U-Factor	ASTM C 1363	25 days
Glass SHGC	IS 16231-2 ISO 9050/ EN 410 / NFRC 300	7 days
Window SHGC	NFRC 201	25 days
Glass VLT	IS 16231-2 ISO 9050/ EN 410 / NFRC 300	7 days
Window air leakage	NFRC 400, ASTM E 283	15 days
Thermal conductivity of frame	ISO/DIS 22007-2.2	7 days

5 SALIENT FEATURES OF INTERNATIONAL WINDOWS ENERGY LABELLING PROGRAMMES [8]

5.1 National Fenestration Rating Council (NFRC) in the US

The NFRC is an independent organisation comprising manufacturers, government bodies, academic institutions, and consumer groups. It develops and revises a uniform information system for the energy performance of fenestration products. The information system includes 3 mandatory parameters i.e. U value, Solar Heat Gain Coefficient (SHGC) and Visible Light Transmittance (VLT) and 2 voluntary parameters i.e. air leakage and condensation resistance (CR) (Figure 1). NFRC accredited simulation labs prepare a computation simulation report on the baseline product's energy performance according to NFRC recommended testing methods. Similarly, NFRC accredited physical testing labs prepare a physical testing report on the baseline product's energy performance according to NFRC recommended testing methods. NFRC licensed Inspection Agencies (IAs) review these test reports to check if the reported energy parameters fall within NFRC recommended tolerance limits, and authorises product certification and issues a Certification Authorisation Report (CAR) valid for 4 years. The manufacturer (licensee) pays participation fees, product line and label usage fees, and IA and lab fees.

Figure 1: A sample NFRC label depicting the 3 mandatory test parameters i.e. U value, SHGC and VLT; air leakage and CR are voluntary test parameters

5.2 Australian Fenestration Rating Council (AFRC) in Australia

The AFRC label compares a window with a base case window (single glazed, clear glass, thermally unbroken aluminium frame). It provides 3 types of information i.e. (1) The heating and cooling performance of the window on a scale of 0-5 stars in steps of ½ (11 point scale); this is valid for all orientations, all Australian climates and a wide range of window sizes, and includes the relative contributions of glass and frame; (2) Indicative per cent reduction in heating and cooling needs for the whole house to keep the house within a comfortable temperature range; (3) U value, SHGC, VLT, fabric fading transmittance, and air filtration. The rating is based on 2 sets of simulations results. The first is done using LBL's WINDOW, THERM and OPTICS software. In the second stage, the window is plugged into the Nationwide House Energy Rating Software (NatHERS) to determine the impact of the window on a model house. Physical testing is used only for unusual and complex window systems. Conservative default values of air leakage can be input into NatHERS.

5.3 British Fenestration Rating Council (BFRC) in the UK

The BFRC uses a 7-point rainbow scale (A++ (best) to E (worst)) (Figure 2). Each colour band corresponds to a range of BFRC energy index measured in kWh/m2/year, which is a function of U value, SHGC and air leakage of the whole window system. A negative energy index implies that the window will lose net heat energy, whereas a positive energy index implies the window will gain net heat energy and become a free heat supplier. The rating process involves the use of a BFRC approved simulator and one of the 4 Independent Agencies (IAs) for verification of simulation results. The BFRC is valid only for standard window size and for a standard UK weather file.

Figure 2: A sample BFRC 7-point rainbow scale label

Table 4 compares the aforementioned international window labelling programmes.

Table 4: A brief comparison of the NFRC, the AFRC and the BFRC

	Type	Parameters considered	Simulation testing	Physical testing	Inspection agency capacity
NFRC	Direct value reporting (no rating/ranking)	Mandatory: U, SHGC, VLT Voluntary: Air leakage, condensation resistance	Yes	Yes	Yes
AFRC	• Star labelling for heating and cooling performance • Indicative per cent reduction in heating and cooling needs • Direct value reporting	U value, SHGC, VLT, fabric fading transmittance, and air filtration	Yes	No	Unclear
BFRC	• 7-point rainbow scale (A++ (best) to E (worst)) • BFRC energy index	BFRC energy index, which is a function of U value, SHGC, air leakage	Yes	No	Yes

5.4 Features that could be applicable in India

A more detailed study of the administrative mechanisms of international windows energy labelling programmes could help address the following:

- We can learn from international programmes such as those described above to invent our own label type - we could either directly report the window thermal and light transmittance parameters like in the NFRC or follow a star labelling system such the ones already used in room air conditioners and refrigerators; else we could invent our own single metric like the BFRC energy index to report and compare the energy performance of windows
- It will be important to decide the type of testing - physical testing or simulation or both - to focus our capacity building initiatives.
- Considering that the windows industry is fairly fragmented, the programme could be launched in phases. Phase 1 could simply be a glass labelling programme. Given the maturity of the supply chain and complexity of performance parameters, it could be an idea to start with a glazing labelling program as a precursor to the window labelling program. Glass being the major component occupying the largest amount of area in the fenestration, this rating program would be representative enough of the windows. In a tropical country like India, where direct solar heat gain is the main source of heat ingress, the solar control performance of the glass would be directly proportional to that of the window and as such can be a good starting point for a labelling mechanism. A glass labelling would be much simpler and easier in terms of both process and inclusion into the system. Then a whole window labelling programme could be started in Phase 2 for prefabricated/factory made windows.

6 CREATING AN ECOSYSTEM TO ENABLE A WINDOWS ENERGY LABELLING PROGRAMME IN INDIA [9]

With significant growth in the real estate sector on the horizon, it is important to understand the challenges in rolling out a window labelling programme for India and potential solutions. Window labelling can help developers and end users choose the right windows for minimising the ingress of heat into buildings, thereby reducing the cooling energy consumption needed for maintaining satisfactory levels of indoor thermal comfort. Beyond energy-related benefits, programmes like these can lend credibility to manufacturers, increase their business and add value to customers. Moreover, there is better awareness in builders and consumers about using energy-efficient windows.

Majority stakeholders across the supply chain view window-labelling as a necessity in India. Windows are being increasingly manufactured in factories and sent to building construction sites as opposed to fabrication in-situ in the past. The industry reckons there is no major technological barrier in rolling out a window labelling programme. The frame (UPVC and aluminium) and glass manufacturers are confident that their products can keep up with energy standards. This can ease the enactment and implementation of a window labelling mechanism. However, there are some challenges that will need addressing:

- The window frame industry is ~80% aluminium and ~20% UPVC. UPVC manufacturers are mainly Europe-based and will be more supportive of a window-labelling program. Within the aluminium subsector, 10-15% is organised and will be willing, whereas the others are local manufacturers and unorganized, who may find it difficult to adopt new standards.
- Lack of adequate testing facilities: only 2 centres in East and West are present in India as of now, capable of performing the testing required for window labelling. At least 2 more centres in North and South are required to cater to the demand which is expected to come.
- Window manufacturing being primarily dominated by the unorganized sector, there are no forums to share knowledge amongst all sectors. Window frame material manufacturers, glass

manufacturers and glass processors are mostly organized but window frame construction and assembly is highly unorganized.
- Poor quality installation with air gaps causing increased heat loss to the surrounding air

Delineated below is a set of high-level recommendations to create an ecosystem to foster a windows energy labelling programme in India:

<u>Market transformation mechanisms</u>

- Government policies related to Smart Cities should advocate the inclusion of energy efficient windows and glazing. We recommend developing sustainably cooled 'Demonstration Projects' in a few sites, piloting innovative window solutions. The calculated energy saving outcomes in these demonstration projects should be highlighted through Government Technology Alerts to create awareness and establish the credibility of HP glazing in enhancing thermal comfort and reducing the building's cooling needs.
- Make ECBC implementation mandatory in all states. Provide governance to ensure strict compliance with all mandatory codes. Over time, develop variants of ECBC or simplified energy efficiency codes/ guidelines to cover smaller commercial buildings. ECBC 2017 prescribes WWR, U-values and SHGC – our analysis shows that even with base ECBC 2017 compliance half of the total energy savings potential can be realised.
- Establish policies to create state-level financial facilities for a low-cost/preferential line of credit to real estate projects with a demonstrably energy-efficient building envelope, including energy-efficient windows.
- Promote the concept of 'Green Leasing' in commercial spaces: the idea is that the building owners could charge a premium rent for an energy efficient space, and the tenant would benefit from enhanced occupant comfort and operational savings achieved through lower energy bills.
- Introduce sustainable rating of architects/architecture firms based on a suitable building performance or energy efficiency quotient (e.g. the average EPI of operational project portfolio). Mandating minimum eligibility criteria for practising architects in terms of these ratings will help ensure a constant push towards the embodiment of energy efficiency and sustainability features in their projects, including energy efficient windows glazing.
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<u>Capacity building mechanisms</u>

- Capacity ramping up in terms of testing, both physical testing and simulation, infrastructure and training and awareness to be scaled up
- Introduce sustainable rating of architects/architecture firms based on a suitable building performance or energy efficiency quotient (e.g. the average EPI of operational project portfolio). Mandating minimum eligibility criteria for practising architects in terms of these ratings will help ensure a constant push towards the embodiment of energy efficiency and sustainability features in their projects, including energy efficient windows glazing.
- Undertake capacity building, training and awareness exercises including setting up a centre of excellence for HP windows and glazing. Facilitate up-gradation of existing curricula across relevant streams/ branches/fields of study to include sustainable cooling techniques.
- Create a robust knowledge-sharing and collaborative platform to bring together stakeholders across the window manufacturing and installation supply-chain from both the organised and unorganised sectors.

PART 2

A MARKET ASSESSMENT OF LOW ENERGY COOLING TECHNOLOGIES

8 INTRODUCTION

In this Part, low energy cooling technologies refer to unconventional cooling technologies that are not as energy intensive as vapour compression cooling. These can be used as either standalone cooling systems or in conjunction with the conventional air-conditioning. These technologies offer advantages of reduced cost or complexity, increased reliability, peak demand reduction, energy savings and GHG reduction. These technologies have been applied at sizeable scales in commercial buildings in India and are known to provide other non-energy benefits, which include improved indoor air quality, noise reduction and integration with Internet of Things (IoT) for better control and monitoring.

The India Cooling Action Plan (2019) identifies promoting the development and commercialization of technology pathways, especially low-energy cooling technologies, which would reduce the energy footprint of active cooling as a priority area. Through the right combination of policy and market drivers, the private sector must be enabled to lead the technology development through innovation and R&D. The technology pathways must include, inter alia, the evolution of not-in-kind technologies for scaled-up adoption.

8.1 Manufacturers' Survey

A detailed questionnaire (Appendix B) was shared with 20+ manufacturers covering the following low energy cooling technologies: Vapour Absorption Machine (VAM) (including solar VAM), radiant cooling, Indirect-Direct Evaporative Cooling (IDEC), Direct Structure Cooling (DSC), desiccant cooling, geothermal cooling and radiative sky cooling. One-to-one in-person or telephonic consultations were conducted with the technical representatives of these manufacturers. The survey aimed to make a market assessment of low energy cooling technologies including information on:

- Description of the technology
- The capacity of the available systems
- Effectiveness in providing thermal comfort
- Cooling efficiency and energy saving potential
- Applicability for Indian conditions, i.e. climate zones, type of buildings
- Current market conditions in India for standalone products – market size, product specs, price, penetration, customer type – residential and commercial
- Discussion on the cost-effectiveness of incorporating low energy cooling technologies, including
- incremental costs and potential pay-back periods

A consolidated form of the relevant responses received has been presented in the following section.

9 A DEEP-DIVE INTO SOME LOW ENERGY COOLING TECHNOLOGIES

9.1 Vapour Absorption Machine (VAM)

Description: Vapour Absorption chillers use water as the refrigerant and Lithium Bromide (LiBr) solution as the absorbent. The process of cooling goes through stages such as evaporation of refrigerant in the evaporator, absorption of refrigerant by concentrated LiBr solution in the absorber, boiling of diluted LiBr solution to generate refrigerant vapour in generator and condensation of refrigerant vapour in the condenser.

Feasibility: VAM can find application in offices, hotels, hospitals, institutions, retail, and industrial cooling and refrigeration. VAM can be used to achieve indoor conditions of 5-30°C and 30%-60% RH. It can be used for year-round application in all the 5 climate zones of India. It is generally not used in residential buildings, but there is a wider possibility of retrofitting VAM in old buildings.

Installation: The prerequisites for the installation of VAM include a cooling tower water temperature of around 32°C, and an unending source of low grade heat or waste heat in the form of steam (4-8 kg/cm^{-2}), hot water, exhaust gas, thermic fluid, natural gas, HSD, circulating pumps, or AHUs. The main components include a vacuum system using lithium bromide (LiBr) as absorbent and water as refrigerant, evaporator, absorber, generator, condenser, absorption pump, and controls; these components are typically manufactured in India, China and Japan. VAM can be either floor-mounted or skid-mounted in the plant room. Typically, installation takes 4-6 months. Installation is limited by the availability of space near the heat source; also, the cost of the supply heat as compared to electricity should be considered.

Operation and maintenance: VAM is generally used at a set point of 7°C chilled water temperature. It can be integrated with VC and other low energy cooling technologies. It can also be integrated with IoT. Vacuum break, poor water quality and corrosion are the main causes of system breakdown, however, it can be restored to normal use within 24 hours by descaling; repair services are generally made available by the manufacturer. A VAM system can go one for 18-20 years of operation.

Performance: The COP of a VAM system can vary between 0.8 and 1.9 depending on the quality of the heat source. The EPI is around 100 kWh/m^2/year.

Commercials: The cost of installation can vary from INR 35,000-1,00,000/TR. The capital cost is about 20% higher than for a VC chiller; however, the operational cost is lower and the payback period can be anywhere between 1-4 years.

Installed capacity: As per data received by manufacturers from 2007 till March 2015 and projections till March 2017, an aggregate of 0.7 million TR of solar VAM (replacing an equivalent amount of conventional air conditioning) is installed in India [1].

Case studies:

Anantara Resorts, Maldives required a tri-generation solution for their new luxury resort. Efficiency, flexibility and reliability were the basic requirements apart from a turnkey solution and guarantees on parameters. It was a complex requirement involving heat recovery from the gen-set exhaust and jacket water, fired steam boilers, absorption chillers and standby electrical chillers. Aqua Chill Systems India Pvt India worked beyond conventional concepts to meet these and designed the most appropriate system for the resort after evaluating various options and combinations. Design and installation of about 120 FCUs with chilled water connections spread across the campus was meticulously done. The entire turnkey execution was done with thorough planning and coordination from design, sourcing, packing, exporting, receipt and installation.

Dheenanath Mangeshkar Hospital, Pune is a classic case of cogeneration based power and cooling system. There are 3 nos. of 1.2 MW gas engines installed, which cater to the power requirement of the hospital blocks. 3 nos. of 320 TR multi-energy absorption chillers, driven by the flue gas and HT jacket water from the engine provide free cooling for the hospital. This helps save nearly 3,500 MW of power annually compared to conventional electric chillers, which is equivalent to the reduction of 4,500 tonnes of CO_2 per year.

9.2 Radiant cooling

Description: Radiant cooling uses actively cooled surfaces to provide thermal comfort primarily through the radiative heat transfer between the human body and the cooled surface. Radiant based HVAC systems provide direct sensible cooling by absorbing heat from the space that is taken away by the chilled water flowing in the pipes embedded in floors, walls or ceilings, or through the externally mounted wall and ceiling panels. The system takes advantage of the considerably higher thermal capacity of water over air. These thermally conditioned surfaces are maintained at a temperature slightly above the local dew point temperature to provide maximum thermal comfort as defined by ASHRAE Standard 55 while avoiding the possibility of condensation. Radiant cooling is highly efficient compared to regular air-conditioning due to the higher chilled water temperature used in the radiant systems and the minimal use of air that is typically used to provide minimum outdoor air needed to maintain optimum indoor air quality (IAQ). A radiant cooling system should be appended with a dedicated outdoor air system (DOAS) to avoid condensation in highly humid conditions – this might increase the initial cost of the system. Also, to avoid condensation, the temperature of the radiation surface must be maintained at a temperature higher than the indoor air dew point temperature, which limits the cooling capacity of the system. To minimise condensation, radiant panels should be part of the ceiling – this gives better control of the chilled water temperature than wall embedded radiant systems.

Feasibility: Radiant cooling can find application in offices, hotels, institutions, retail, in some healthcare facilities, and other commercial spaces like warehouses, industrial spaces, libraries, and airports. India has more than 4 million sqft of radiant cooled built-up area (BUA). Modular radiant panels can be retrofitted in old buildings. It can be used to achieve indoor conditions of 22-26°C and 30%-60% RH with a dedicated outdoor air system (DOAS). Up to 15°C is possible to achieve in conjunction with a VC system. It can be used in all the 5 climate zones of India: warm and humid (with a DOAS), composite, hot and dry, temperate and cold (in the heating mode). It is best suited for use in the dry season but can be used the whole year round by integrating it with a VC system. It is generally not used in residential buildings, but there is a wider possibility of retrofitting VAM in old buildings.

Installation: The main components include PERT/PEX pipes, panels, pumps, manifolds, and a chilled water source; these components are typically manufactured in India and Europe (CE marked). It can be either ceiling/wall-mounted or floor/slab-embedded (in which case the floor height may increase by 30-40 mm). Typically, 800 sqft of radiant cooled BUA can be installed in a day.

Operation and maintenance: Radiant cooling is generally used at a set point of 25°C for cooling and 21°C for heating. It can be integrated with IoT, waste heat, VC and other low energy cooling technologies. Air gaps and pump/valve failure are the main causes of system breakdown, however, it can be restored to normal use within ½ day; the manufacturer generally makes repair services available. A radiant cooling system can last for 20-25 years of operation.

Performance: Radiant cooling typically consumes 30%-50% less energy/area as compared to VC. Around 35% of energy consumption can be attributed to fresh air systems.

Infosys conducted a study [10] in two identical buildings at its Hyderabad campus (35,000 m2 area), with conventional air-conditioning complying with ASHRAE standards in one and with the radiant cooling system in the other. The conventional air-conditioning EPI was recorded as 38.7 kWh/m2 and the radiant cooling EPI was recorded as 25.7 kWh/m2. This showed that the radiant cooling system was 33% lower in energy consumption compared to the conventional air-conditioning system, which was extremely efficient, to begin with, for the year 2011-12.

In another case [11], Tech-Mahindra, Hyderabad installed a radiant cooling system of 356 m2 area, and it was found that the radiant cooling system was 18% more efficient than the conventional cooling system.

Commercials: The cost of installation can vary from INR 30-35/sqft. The capital cost is (approximately): underfloor INR 250/sqft; ceiling INR 550/sqft; wall INR 350/sqft; slab INR 150/sqft; however, the operational cost is lower and the payback period can be anywhere between 1-5 years.

A cost comparison suggests at Infosys suggested that while conventional air-conditioning would cost Rs.322/sqft, radiant cooling would cost Rs.319/ sqft.

Installed capacity: As per data received by four manufacturers of radiant cooling systems from 2008 till March 2016 and projections till March 2017, an aggregate of approximately 4 million sq. ft. built-up area in India is cooled using radiant cooling, replacing approximately 18,000 TR of conventional air conditioning in 73 large commercial buildings [1].

Case study: Oorja Energy Engineering Services provided its sustainable cooling solution to RA Chem Pharma Ltd in Hyderabad who wanted to build a warehouse for storing their final product, which is a bulk drug. The total area of the warehouse was around 13,000 sqft and the total cooling load was around 150 TR. Using Oorja's radiant cooling panels, they were able to reduce the cooling load to 75 TR as the panels come with heat reflecting foils. The reflecting surface faces the roof of the warehouse and all the heat being radiated from the roof is reflected back and exhausted with the help of ventilators. The entire system was installed on the ceiling and walls of the warehouse. The system has been operational since 2017 and has delivered significant energy savings.

9.3 Indirect-Direct Evaporative Cooling (IDEC)

Description: IDEC is a process in which the hot ambient air is pre-cooled indirectly without adding moisture to the outdoor air (by using one side wet air to air polymer plate heat exchanger) at the first stage. In the second stage, the pre-cooled air passes through a wet pad having a large surface area or water spray bank. The pre-cooled air picks up moisture from this process and gets further cooled. Since the outdoor air is sensibly pre-cooled in the first stage, without adding any moisture hence less moisture is transferred in the direct stage to reach the lower supply air temperatures. The result is cooler air with minimum water use, compared to a traditional evaporative cooler which adds almost double the quantity of moisture in the air.

Feasibility: IDEC can find application in offices, hotels, institutions, retail, in some healthcare facilities, and industrial spaces. It can be used to achieve indoor conditions of 4-5°C lower temperature and around 60% lower RH than evaporative cooling. It is best suited for use in the composite, hot and dry, and temperate climate zones. It can be used the whole year round but the performance is compromised in the monsoon season. Retrofitting is possible.

Installation: Water is a prerequisite. The main components are HX, CELdek cooling pads, blowers, motors, and a water distribution system; these components are typically manufactured in India. It is available in wall-mounted and ducted configurations (floor-mounted is suitable for outdoor installations). Installation generally takes just as long as that for a VC system.

Operation and maintenance: IDEC is generally used at a set point of 28(+/-2)°C. It can be integrated with IoT, waste heat, VC and other low energy cooling technologies. Poor water quality, improper air filters and negligent maintenance are the main causes of system breakdown, however, it can be restored to normal use within 2-14 days; the manufacturer generally makes repair services available. A radiant cooling system can last for 7-15 years of operation.

Performance: IDEC can deliver up to 5 ISEER. It consumes around ½ kWh per 100 CFM and can save 50%-60% energy and refrigerant charge as compared to conventional VC.

Commercials: It costs as much as a 5-star inverter AC, with a payback of 1-2 years.

Installed capacity: As per data received from four manufacturers of IDEC systems from 2008 till March 2015 and projections until March 2017, the aggregate capacity of approximately 43 million cubic feet per minute (air flow) has been installed in India. This equates to replacement of approximately 0.1 million TR or conventional air conditioning in more than 800 buildings [1].

Case studies:

The following sites have installed IDEC systems by Roots Cooling Systems Pvt Ltd:

- Britannia Industries Ltd., Gujarat, Bangalore, Assam
- MRF, Chennai,
- Graziano, Gujarat
- WHPL, Pune,
- Hella India, Gujarat
- Koshyma Engg., Bangalore
- Densol, Bangalore
- Hindustan Coca-cola

TORO's Ambiator technology is cost-effective and climate appropriate. It can provide space temperatures below 27ºC and humidity 55 ±5% even if the ambient temperatures exceed 45ºC during the hot Indian summer climate. The seasonal cooling EER during dry summer remains within 18-20 W/W. It is available in window and split configurations.

9.4 Direct Structure Cooling (DSC)

Description: Structure cooling aims to reduce the mean radiant temperature by extracting heat from the structure. This is achieved by circulating water at ambient temperature in pipes embedded over slabs to extract heat from the structure, thereby preventing it from getting too hot. The higher thermal mass of water delays the transfer of heat from the surroundings to the interiors of the structure. The circulated water drains heat from the structure and the heated water flows to the radiator where it gives away the heat gained and goes back to the tank for recirculation. It is a closed loop system so water requirement is one-time. There is no chilling of water or refrigerants required – only the pump takes up energy.

Feasibility: DSC can find application in offices, hotels, institutions, retail, healthcare facilities, and industrial spaces. It is suited for use in all the climate zones of India for year-round application. DSC can drastically reduce the diurnal range of temperature and relative humidity within the structure. DSC measures provide insulation even while providing natural ventilation. The indoor temperature during the peak of summer can be close to the neutral temperature.

Installation: A loop of plastic pipes is laid between the slab screed and the tiling. Water from an underground water tank is circulated in the pipes that are cooled by a radiator that cools the water through the night sky radiation.

Commercials: In terms of capital cost, DSC is 50% less costly than a conventional HVAC system and the recurring energy cost is a mere less than 10% of a conventional system. The total life cycle costing of DSC is around INR 6/sqft/year as compared to INR 30/sqft/year for a conventional system.

Installed capacity: As per data shared by manufacturers from 2005 till March 2014 and projections up to March 2017, an aggregate of approximately 0.6 million sq. ft. built-up area in India uses structure cooling technology, replacing approximately 4,600 TR or conventional air conditioning in 28 large commercial buildings [1].

Case study: The city of Nashik in Maharashtra located at an elevation of 700m above mean sea level, has a maximum Dry Bulb Temperature of 37^{0}C in April and May, while minimum temperatures can reach 10^{0}C in January and February. The case study office building is a ground + 2 storied building with flat roof admeasuring 258.5 sq.m carpet area. The building is oriented in the north-south direction. Entrance is from the North while the South wall is common to the adjacent plot building. WWR on North is 35%, East 20% and West 57%. Terrace on the second floor is 37 sqm. The building envelope is made of a double wall with brick cladding and air gap. The DSC system installed at the office building by Panasia Engineers Pvt Ltd in Nashik comprises 21 mm plastic pipes laid out in a grid on the plinth of all floors. The system is designed to remove 242 Btu/sqft/ hour of heat from the plinth mass of the structure. The thermal conductance of the pipe in the grid is 4.5 W/^{0}C or 77 Btu/hour for every 1 m of the pipe. Due to DSC, the diurnal range of temperature and RH was greatly reduced: the outdoor diurnal range of DBT was 14.7^{0}C as compared to indoor DBT range of 3^{o}C. Similarly, outdoor diurnal range of Relative Humidity (RH) was 71% in contrast to indoor RH range of 27.6%.

10 POTENTIAL MARKET BARRIERS

Whilst there are many low energy cooling options available in the Indian market, almost none of them have reached their full potential in terms of market maturity to replace conventional VC air-conditioning. As mentioned earlier, the India Cooling Action Plan also recognises the importance of mainstreaming these low energy cooling technologies to offset the growing demand of air-conditioning. The survey brought to the fore the following market barriers to their mainstreaming:

- Lack of awareness among consumers
- Limited market players
- Higher upfront cost compared to conventional air-conditioning (sometimes)
- Limited technology know-how and the unwillingness of HVAC consultants to experiment with new cooling solutions
- Limited government support

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APPENDIX A

Scoping Window Energy Testing in India

1. Which parameters that relate to the energy performance of windows are tested at your facility? How long does it take to carry out the tests/unit? How much does it cost? Please indicate ranges wherever possible.

	Whole window testing *OR* glazing only	Testing standard referred (E.g. NFRC 300-2010 / ISO 9050 / others)	Test duration	Price/unit (INR)
U-Factor				
Solar Heat Gain Coefficient (SHGC)				
Visible Light Transmittance (VLT)				
Air leakage				
Condensation resistance				

2. Can the impact of shading/films/window attachments be tested/quantified?
3. What are some typical sample specs? Size? Material?
4. How many orders are accepted annually? Order size? Typical waiting time?
5. How many technicians work at your testing facility? What training have they received? What are their skills and qualifications?
6. What is the typical administrative process to have a product tested?
7. Do you supplement physical testing with software simulations/models like the ones published by Lawrence Berkeley Lab?
8. Please can you mention the names of some windows manufacturers who get their products tested at your facility?
9. What changes have you observed in this domain after the rolling out of ECBC v.1 2007 and v.2 2017 and its adoption in select states?

10. How should India's window energy testing infrastructure be improved/strengthened to make windows energy labeling program possible?
11. What are the opportunities and challenges you foresee if the Bureau of Energy Efficiency (BEE) were to instate a windows energy labeling program in India?
12. Please can you recommend the name and contact details of someone you know who can/should take this survey?

APPENDIX B

LOW ENERGY COOLING TECHNOLOGIES: MANUFACTURER SURVEY

SECTION A: INTRODUCTION

1. Company name:
2. Date of establishment:
3. Office location(s) and areas served:
4. Products: mention the product
5. Capacity installed so far and what is the CAGR in sales over the past 5 years:
6. Please indicate the percentages of sales in the following periods

☐ March to June- % ☐ July to October- % ☐ November to February- %

SECTION B

FEASIBILITY

1. Please highlight typical sectors of application.

☐ Office ☐ Hotel ☐ Healthcare ☐ Educational buildings ☐ Retail ☐ Industries

☐Transit buildings ☐Assembly buildings ☐ Restaurants ☐ Others (please specify)

2. What indoor temperatures and RH profiles can be achieved with this cooling product? (minimum and maximum)

Temperature range: °C Relative humidity range: %

3. Which climatic zones can this be typically used in? (Please highlight)

☐Hot-dry ☐ Warm-humid ☐ Composite ☐ Temperate

4. Is it viable for year-round application? In which months/seasons can it NOT be used?

PRODUCT INFO: TECHNICAL

5. What are the main components of the system?
6. What configurations of the system are available (for e.g. wall-mounted, ceiling-mounted)?
7. What are the prerequisites for installation? (if any)
8. Where are these components manufactured?
9. Where was the product tested? Could you provide details onthe testing conditions?
10. What is the typical COP/EER of the system?
11. What are the typical set points for which the systems are designed?
12. How does this cooling system compare with a typical vapour compression system?
13. What is its annual energy consumption (kWh) or energy index (kWh/m^2)?
14. Is there a provision for retro-fitting in old building constructions? (Yes/No)
15. What is the typical installation time?
16. What is the approximate cost of installation per tonnage?
17. What are reported/observed installation challenges?
18. Please comment on the durability of the system. What is its typical life-time?
19. Please comment on the occupants' satisfaction in terms of thermal comfort and IAQ on a scale 1 to 5 (5 being most comfortable).

PRODUCT COMMERCIALS

20. How is it priced?
21. What is its typical payback period?
22. Who are the other major market players?
23. What is your market share?

SECTION C: O&M

1. Why do systems typically breakdown?
2. How quickly can it be restored?
3. Do you provide repair services? (Yes/No)

SECTION D: FUTURE SCOPE

1. Is there scope for integrating it with waste heat and other low-grade energies? (Yes/No)
2. Is there scope for integration with conventional systems and/or other low energy cooling technologies? (Yes/No)
3. What technological developments are under way?
4. Is there any provision to integrate with IoT for auto control measures to ensure energy efficiency? (Yes/No)
5. Is the technology registered with any green building rating system? (Yes/No)

SECTION E: OUTREACH

1. Has there been any collaboration with industry R&D or any research/academic institutes?
2. Have you explored similar technologies in other countries?
3. Do you foresee overseas potential for the product?
4. Has it gained enough exposure in any workshops/symposiums. Which ones?
5. What do you perceive as potential market inhibitors?
6. Please detail any 1 success story in NOT more than 150 words.

Name and designation of the respondent:
Phone:
Email:

Please can you also provide details (Name, contact details) of your patrons who use this technology/product.