REHVA

EUROPEAN GUIDEBOOK

Resilient Cooling Design Guidelines

EBC

Energy in Buildings and Communities Programme

IEA-EBC Annex 80 “Resilient Cooling of Buildings”

REHVA EDITION

NO. 33 - 2024

Federation of European Heating, Ventilation and Air Conditioning Associations

Resilient Cooling Design Guidelines

REHVA Task Force

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Table of Contents

Executive Summary

These guidelines are a collaborative effort between the Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) and the Energy in Buildings and Communities (EBC) programme of the International Energy Agency; Annex 80: Resilient Cooling of Buildings project. It draws on the expertise of scientists from diverse institutions in architecture, engineering, building science, and building physics.

The global rise in energy consumption for cooling residential and non-residential buildings, coupled with increased indoor overheating, is a pressing concern. This surge is driven by various factors, including urbanization, climate change, heightened comfort expectations, economic growth, and the accessibility of air conditioning systems. Moreover, disruptive events like extreme heat and heatwaves are becoming more frequent, expected to be commonplace by mid-century. The trajectory toward increased cooling demand is undeniable, necessitating a shift toward sustainable solutions.

Resilient cooling aims to mitigate heat stress and maintain safe building conditions during externally induced disruptions, going beyond mere thermal comfort. This Guidebook focuses on designing cooling systems that are resilient to such challenges.

While a plethora of suitable technologies and solutions exist, many face practical and financial barriers hindering widespread adoption. Some technologies require further development to achieve readiness. Conventional design emphasizes optimizing performance within predetermined parameters, while resilient design prioritizes adaptability and risk mitigation. Resilient design demands a collaborative, innovative approach with a longer timeframe. Therefore, action is imperative for policymakers, stakeholders, researchers, professionals, and industry players.

This Guidebook aims to assist practitioners in implementing highly efficient, low-carbon, resilient cooling solutions, contributing to a sustainable built environment. It identifies key challenges, opportunities, and frameworks associated with building design, exploring innovative concepts to address these issues. It provides an in-depth analysis of various technologies, practices, and simulation approaches, with a focus on disruptive events such as heatwaves and power outages.

The main contents of this Guidebook include definitions of resilient cooling for buildings, metrics and key performance indicators, simulation tools and evaluation methods, inputs for performance assessment, frameworks for future weather data development, technological profiles of active and passive cooling solutions and components, and two demonstration case studies – one for new construction and one for existing building renovation.

The target audience includes practitioners in building design, architectural firms, building services sectors, consulting engineers, firms, national authorities, building owners, tenants, policymakers, government officers, and building services institutions. It is relevant for small and mid-size facilities, residential and commercial buildings, and both new construction and existing buildings in terms of operation, management, and maintenance.

Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 30 IEA participating countries and to increase energy security through energy research, development, and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes (TCPs). The mission of the IEA Energy in Buildings and Communities (IEA EBC) TCP is to support the acceleration of the transformation of the built environment towards more energy efficient and sustainable buildings and communities, by the development and dissemination of knowledge, technologies, processes, and other solutions through international collaborative research and open innovation. (Until 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme (ECBCS).)

The high priority research themes in the EBC Strategic Plan 2019-2024 are based on research drivers, national programmes within the EBC participating countries, the Future Buildings Forum (FBF) Think Tank Workshop held in Singapore in October 2017, and a Strategy Planning Workshop held at the EBC Executive Committee Meeting in November 2017. The research themes represent a collective input of the Executive Committee members and Operating Agents to exploit technological and other opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy technologies, systems, and processes. Future EBC collaborative research and innovation work should also focus on these themes.

At the Strategy Planning Workshop in 2017, some 40 research themes were developed. From those 40 themes, 10 themes of special high priority were extracted, taking into consideration a score that was given to each theme at the workshop. The 10 high priority themes can be separated in two types namely 'Objectives' and 'Means'. These two groups are distinguished for a better understanding of the different themes.

Objectives

The strategic objectives of the EBC TCP are as follows:

- reinforcing the technical and economic basis for refurbishment of existing buildings (including financing, engagement of stakeholders, and promotion of co-benefits);
- improvement of planning, construction, and management processes to reduce the performance gap between design stage assessments and real-world operations;
- the creation of 'low tech', robust, and affordable technologies;
- the further development of energy efficient cooling in hot and humid or dry climates, avoiding mechanical cooling if possible;
- the creation of holistic solution sets for district level systems considering energy grids, overall performance, business models, engagement of stakeholders, and transport energy system implications.

Means

The strategic objectives of the EBC TCP will be achieved by the means listed below:

- the creation of tools for supporting design and construction through to operations and maintenance, including building energy standards and life cycle analyses (LCA);
- benefitting from 'living labs' to provide experience of and overcome barriers to adoption of energy efficiency measures;
- improving smart control of building services technical installations, including occupant and operator interfaces;
- addressing data issues in buildings, including non-intrusive and secure data collection;
- the development of building information modelling (BIM) to increase building resilience opportunities, from design and construction through to operations and maintenance.

The themes in both groups may be the subjects of new Annexes, but what distinguishes them is that the 'objectives' themes are final goals or solutions (or parts thereof) for an energy efficient built environment, while the 'means' themes are instruments or enablers to reach this a goal. These themes are explained in more detail in the EBC Strategic Plan 2019-2024.

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with ongoing (in May 2024) projects identified with an asterisk (*):

ANNEX 01: Load/Energy Determination of Buildings Completed

ANNEX 02: Ekistics and Advanced Community Energy Systems

ANNEX 03: Energy Conservation in Residential Buildings

ANNEX 04: Glasgow Commercial Building Monitoring

ANNEX 05: Air Infiltration and Ventilation Centre (*)

ANNEX 06: Energy Systems and Design Communities

ANNEX 07: Local Government Energy Planning

ANNEX 08: Inhabitant Behaviour with Regard to Ventilation

ANNEX 09: Minimum Ventilation Rates

ANNEX 10: Building HEVAC System Simulation

ANNEX 11: Energy Auditing

ANNEX 12: Windows and Fenestration

ANNEX 13: Energy Management in Hospitals

ANNEX 14: Condensation and Energy

ANNEX 15: Energy Efficiency in Schools

ANNEX 16: Building Energy Management Systems-User Interfaces and System Integration

ANNEX 17: Building Energy Management Systems - Evaluation and Emulation Techniques

ANNEX 18: Demand Controlled Ventilation Systems

ANNEX 19: Low Slope Roof Systems

ANNEX 20: Air Flow Patterns within Buildings

ANNEX 21: Environmental Performance

ANNEX 22: Energy Efficient Communities

ANNEX 23: Multizone Air Flow Modelling

ANNEX 24: Heat, Air and Moisture Transport

ANNEX 25: Real Time HEVAC Simulation

ANNEX 26: Energy Efficient Ventilation of Large Enclosures

ANNEX 27: Evaluation and Demonstration of Domestic Ventilation Systems

ANNEX 28: Low Energy Cooling Systems

ANNEX 29: Daylight in Buildings

ANNEX 30: Bringing Simulation to Application

ANNEX 31: Energy Related Environmental Impact of Buildings

ANNEX 32: Integral Building Envelope Performance Assessment

ANNEX 33: Advanced Local Energy Planning

ANNEX 34: Computer-Aided Evaluation of HVAC System Performance

ANNEX 35: Control Strategies for Hybrid Ventilation in New and Retrofitted Office Buildings (HybVent)

ANNEX 36: Retrofitting in Educational Buildings - Energy Concept Adviser for Technical Retrofit Measures

ANNEX 37: Low Exergy Systems for Heating and Cooling

ANNEX 38: Solar Sustainable Housing

ANNEX 39: High Performance Thermal Insulation Systems (HiPTI)

ANNEX 40: Commissioning of Building HVAC Systems for Improving Energy Performance

ANNEX 41: Whole Building Heat, Air and Moisture Response (MOIST-EN)

ANNEX 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (COGEN-SIM)

ANNEX 43: Testing and Validation of Building Energy Simulation Tools

ANNEX 44: Integrating Environmentally Responsive Elements in Buildings

ANNEX 45: Energy-Efficient Future Electric Lighting for Buildings

ANNEX 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)

ANNEX 47: Cost Effective Commissioning of Existing and Low Energy Buildings

ANNEX 48: Heat Pumping and Reversible Air Conditioning

ANNEX 49: Low Exergy Systems for High Performance Buildings and Communities

ANNEX 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings

ANNEX 51: Energy Efficient Communities

ANNEX 52: Towards Net Zero Energy Solar Buildings

ANNEX 53: Total Energy Use in Buildings: Analysis & Evaluation Methods

ANNEX 54: Analysis of Micro-Generation & Related Energy Technologies in Buildings

ANNEX 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost (RAP-RETRO)

ANNEX 56: Cost-Effective Energy & CO_2 Emissions Optimization in Building Renovation

ANNEX 57: Evaluation of Embodied Energy and CO_2 Equivalent Emissions for Building Construction

ANNEX 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements

ANNEX 59: High Temperature Cooling and Low Temperature Heating in Buildings

ANNEX 60: New Generation Computational Tools for Building & Community Energy Systems

ANNEX 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings

ANNEX 62: Ventilative Cooling

ANNEX 63: Implementation of Energy Strategies in Communities

ANNEX 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles

ANNEX 65: Long Term Performance of Super-Insulating Materials in Building Components and Systems

ANNEX 66: Definition and Simulation of Occupant Behavior in Buildings

ANNEX 67: Energy Flexible Buildings

ANNEX 68: Design and Operational Strategies for High IAQ in Low Energy Buildings

ANNEX 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings

ANNEX 70: Building Energy Epidemiology: Analysis of Real Building Energy Use at Scale

ANNEX 71: Building Energy Performance Assessment Based on In-situ Measurements

ANNEX 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings

ANNEX 73: Towards Net Zero Energy Public Resilient Communities

ANNEX 74: Competition and Living Lab Platform

ANNEX 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency & Renewables

ANNEX 76: EBC Annex 76 / SHC Task 59 Renovating Historic Buildings Towards Zero Energy

ANNEX 77: EBC Annex 77 / SHC Task 61 Integrated Solutions for Daylighting and Electric Lighting

ANNEX 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications (*)

ANNEX 79: Occupant-Centric Building Design and Operation (*)

ANNEX 80: Resilient Cooling of Buildings (*)

ANNEX 81: Data-Driven Smart Buildings (*)

ANNEX 82: Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems (*)

ANNEX 83: Positive Energy Districts (*)

ANNEX 84: Demand Management of Buildings in Thermal Networks (*)

ANNEX 85: Indirect Evaporative Cooling (*)

ANNEX 86: Energy Efficient Indoor Air Quality Management in Residential Buildings (*)

ANNEX 87: Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems (*)

ANNEX 88: Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings (*)

ANNEX 89: Ways to Implement Net-zero Whole Life Carbon Buildings (*)

ANNEX 90: EBC Annex 90 / SHC Task 70 Low Carbon, High Comfort Integrated Lighting (*)

ANNEX 91: Open BIM for Energy Efficient Buildings (*)

ANNEX 92: Smart Materials for Energy-Efficient Heating, Cooling and IAQ Control in Residential Buildings (*)

Working Group on Energy Efficiency in Educational Buildings (EBC Annex 15)

Working Group on Indicators of Energy Efficiency in Cold Climate Buildings

EBC Annex 36 Extension Working Group

Working Group on HVAC Energy Calculation Methodologies for Non-residential Buildings

Working Group on Cities and Communities

Working Group on Building Energy Codes (*)

REHVA - Federation of European Heating, Ventilation and Air Conditioning Associations

REHVA was founded in 1963 and is a European professional federation that joins other national associations of building services engineers. Today, REHVA represents more than 120,000 HVAC designers, engineers, technicians, and experts from 26 European countries. REHVA is dedicated to the improvement of health, comfort, and energy efficiency in all buildings and communities. REHVA provides its members with a platform for international networking and knowledge exchange, contributes to technical and professional development, follows European Union policy developments, and represents the interests of its members in Europe and the rest of the world. REHVA's mission is to promote energy-efficient, safe, and healthy technologies for building mechanical services by disseminating knowledge among professionals and practitioners in Europe and beyond. The REHVA Guidebook series is amongst the most important tools used to diffuse knowledge on the latest developments and advanced technologies, providing practical guidance to practitioners. REHVA has published over 30 Guidebooks. REHVA would like to express its sincere gratitude to the authors of this Guidebook for their invaluable work.

Member countries of REHVA

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List of abbreviations

AC .... Alternating Current
ACH................. Air Change Rate
AHU .... Air Handling Unit
AOS .... Accurate Optimal Solutions
ASHRAE.......... American Society of Heating, Refrigeration and Airconditioning Engineers
ASTM .... American Society for Testing and Materials
AWD .... Ambient Warmness Degree
BACS............... Building Automation and Control System
BB101.............. Building Bulletin
BEM .... Building Energy Model
BI .... Bayesian Inference
BPS .... Building Performance Simulation
BS .... British Standard
BSM................. Building Simulation Model
CAPEX .... Capital Expenditure
CCHP............... Combined Cooling, Heat, and Power
CCOR .... Climate Change Overheating Resistivity
CEM .... Cool Envelope Material
CFC .... Chlorofluorocarbon
CMIP6 .... World Climate Research Programme (6th phase)
CNG................. Compressed Natural Gas
COP .... Coefficient of Performance
CORDEX......... Coordinated Regional Climate Downscaling Experiment
COSMO-CLM..Climate Limited-area Modelling Community
CR.................... Cool Roof
CWEC .... Canadian Weather Year for Energy Calculation
DC .... Direct Current
DHW .... Domestic Hot Water
DOA .... Dedicated Outdoor Air
DOE................. Department of Energy (U.S.)
EER .... Energy Efficiency Ratio
EN.................... European Standard

EPBD............... Energy Performance of Buildings Directive
EPS .... Emergency Power Supply
EPW................. Energy Plus Weather File format
ES-SO .... European Association for Solar Shading
FOS.................. Final Optimal Solution
GA .... Genetic Algorithm
GCMs .... Global Climate Models
GUI .... Graphical User Interface
GWP .... Global Warming Potential
He .... Hours of Exceedance
HVAC.............. Heating Ventilation and Air Conditioning
HWY .... Heat Wave Year
I/O.................... Input/Output
ID..................... Identification
IEA EBC ....International Energy Agency: Energy in Building and Community Programme
IOD .... Indoor Overheating Degree
IPCC .... The Intergovernmental Panel on Climate Change
ISO................... International Organization for Standardization
KPI................... Key Performance Indicator
LEED............... Certification Scheme
MAD................ Maximum Absolute Difference
MOGA............. Multi Objective Genetic Algorithm
MVC................ Mechanical Ventilative Cooling
NBR................. Brazilian Regulation
NC .... Night Cooling
NETCDF.......... Format Type
NMBE .... Normalised Mean Bias Error
NVC................. Natural Ventilative Cooling
ODP .... Ozone Depletion Potential
OEF .... Overheating Escalation Factor
OH .... Overheating
PCM................. Phase Change Materials
PCS .... Personal Comfort System
PECS .... Personalized Environmental Control Systems

PHHI................ Percentage occupied Hours within Heat Index range
PHS.................. Predicted Heat Strain
PMV .... Predicted Mean Vote
PPD.................. Percentage Persons Dissatisfied
PV.................... Photovoltaics
RCD................. Resilient Cooling Design
RCM .... Regional Climate Model
RCP .... Representative Concentration Pathway
RH .... Relative Humidity
RMSE .... Root Mean Square Error
RSWY .... Reference Summer Weather Year
SCOP .... Seasonal Coefficient of Performance
SDGs .... Sustainable Development Goals
SEER .... Seasonal Energy Efficiency Rating
SET .... Standard Effective Temperature
SHGC .... Solar Heat Gain Coefficient
SRI................... Solar Reflective Index
TABS............... Thermo Active Building Systems
TBM .... Technical Building Management
TES.................. Thermal Energy Storage
TMY .... Typical Meteorological Year
TRL .... Technology Readiness Level
TRT .... Thermal Response Test
UN .... United Nations
UPS.................. Uninterruptible Power Supply
VE.................... Virtual Environment
VRF .... Variable Flow Refrigerant
WBGT .... Wet Bulb Globe Temperature
WCRP.............. World Climate Research Programme
We .... Weighted Exceedance
WRF .... Weather Research and Forecasting
WUMTPO .... Overall Weighted Unmet Thermal Performance
WWR............... Window to Wall Ratio

1 Introduction

This chapter introduces the reader to the scope, concept, methodology, background information, and framework of this design guideline. It concludes with six practical tips for practitioners.

1.1 General Context

The world is seeing a rapid increase in the cooling of buildings (Dean et al., 2018). This is driven by multiple factors, such as urbanization and densification, climate change, elevated comfort expectations, and economic growth in hot and densely populated regions of the world. Additionally, disruptive events, such as extreme heat and heat waves, are occurring more often and are expected to become a common phenomenon by mid-century. The cooling demand is expected to increase in the coming years. It is therefore essential that this development is steered in toward sustainable solutions.

Given this context, this Guidebook is intended to support practitioners in implementing highly efficient, low-carbon, resilient cooling solutions, technologies, and strategies and contributing to a sustainable built environment. Resilient cooling aims to avoid heat stress for people and to maintain safe and operable conditions in buildings in the event of externally induced disruptions. It therefore goes beyond the upkeep of thermal comfort. This Guidebook focuses on the design of cooling that is resilient to such disruptions.

This Guidebook is an output of the international research project of the Energy in Buildings and Communities (EBC) programme, Annex 80: Resilient Cooling of Buildings. The knowledge is provided by a group of scientists from numerous institutions in various fields such as architecture, engineering, building science, and building physics. Further information on Annex 80 and its outcomes can be found at https://annex80.iea-ebc.org/.

1.2 Definitions of Resilience

The Sustainable Development Goals (SDGs) developed by the United Nations (U.N.) place resilience at the core of their objectives, which is reflected in a number of their targets (Jacob et al., 2018). The U.N. General Assembly Resolution 71/276 (Assembly, 2017) describes resilience as “the ability of a system, community, or society exposed to hazards to resist, absorb, accommodate, adapt to, transform, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management”. ISO 15392 (ISO 15392:2019) characterizes resilience as the “ability to anticipate and adapt to, resist or quickly recover from a potentially disruptive event, whether natural or man-made.” ISO 21931-1 (2022) defines resilience as the “ability to resist, adapt to, or quickly recover from potentially disruptive events or conditions, whether natural or anthropogenic, in order to maintain or restore the intended service.” The above definitions are general, and there is a need to interpret them for a specific emergency affecting the built environment. In the context of buildings, these definitions promote the anticipation and counteraction of future disruptions and their effect on the building’s structure, building services, technical equipment, and, most importantly, the definition depends on its users.