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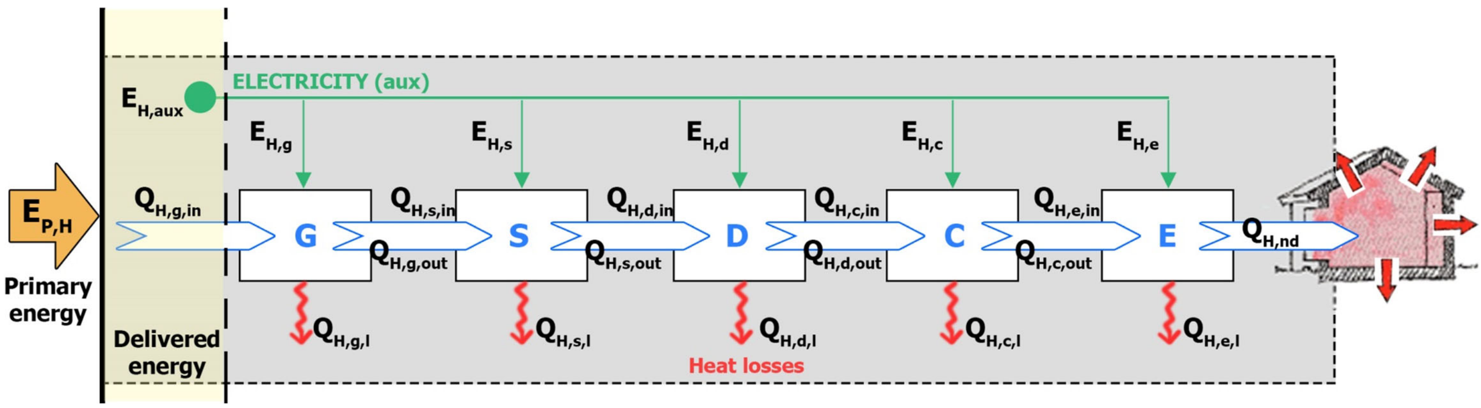
Energy in Buildings and Communities Programme

International Energy Agency

EBC Working Group Final Report: HVAC Energy Calculation Methodologies for Non-residential Buildings

Energy in Buildings and Communities Technology Collaboration Programme

November 2020



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EBC Working Group Final Report: HVAC Energy Calculation Methodologies for Non-residential Buildings

A Survey of National Methodologies, and Relevant National and International Standards

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Energy in Buildings and Communities Technology Collaboration Programme

November 2020

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Participating countries in the EBC TCP: Australia, Austria, Belgium, Brazil, Canada, P.R. China, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Republic of Korea, the Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, Turkey, United Kingdom and the United States of America.

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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 and 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 have its 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 have been 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 operation;
- 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 taking into account 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 analysis (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) as a game changer, from design and construction through to operations and maintenance.

The themes in both groups can be the subject for new Annexes, but what distinguishes them is that the 'objectives' themes are final goals or solutions (or part of) for an energy efficient built environment, while the 'means' themes are instruments or enablers to reach such 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 completed projects identified by (*) and joint projects with the IEA Solar Heating and Cooling Technology Collaboration Programme by (☼):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC 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: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- 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: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC 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: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: ☼ Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)

Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: ☼ Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for 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 and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO2 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 and 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: Indoor Air Quality Design and Control in Low Energy Residential Buildings (*)
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings
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Annex 74: Competition and Living Lab Platform
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Annex 76: ☼ Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions
Annex 77: ☼ Integrated Solutions for Daylight 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
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

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)

Working Group - HVAC Energy Calculation Methodologies for Non-residential Buildings (*)
Working Group - Cities and Communities
Working Group - Building Energy Codes

Contents

Executive Summary

The real performance of building energy systems, especially combination of systems such as HVAC systems is still poorly understood. Metrics to obtain information about real performance are essential for prediction of performance and development of supporting design and decision tools. Above all, the calculation methods of energy use (consumption) are the most important and dependable metrics of building energy performance and it is one of the focal areas of the IEA EBC TCP. A common challenge for countries and regions seems to be in the complexity and variety concerning non-residential building functions as well as technical building systems (building services).

The objectives of this WG are;

- To collect world-wide technical documents on energy use calculation methodologies for HVAC systems in non-residential buildings and on their rationale including information on their validation;
- To analyse the collected documents and define methodology characteristics which are appropriate for broader utilization as best-practice examples;
- To identify the problems of modelling of core energy-saving functions of HVAC systems in their energy calculation methodologies. The problems can be future R&D themes.

Seven national building energy calculation methodologies (Australian, Germany, Italy, Japan, Switzerland, United Kingdom and United States of America), relevant national standards for HVAC equipment, relevant international standards for HVAC equipment and international standards for building energy calculation methods (ISO and CEN) are reviewed and analyzed in this report.

The characteristics of the calculation methods are described in this report from the aspects of 1) categorization of building and space usage, 2) space unit and zoning rules, 3) types of HVAC systems and heat sources, 4) input values for ventilation rate, 5) representation of energy efficiencies of heat sources, 6) representation of energy efficiencies of fan and pump systems, 7) consideration of the effect of commissioning and initial adjustment, 8) referenced standards for components' test and design of systems, 9) techniques to simplify the preparation of input data, 10) completeness of documentation on the calculation rationale and algorism, and 11) information on calculation process validation.

In this project, national documents for the logic and rationale of energy calculation for HVAC systems have been analyzed. It requires considerable work to understand and interpret these, partly because there seems to be background presuppositions and national experiences behind the documents, even though the documents have been prepared in a very transparent way. The outputs from this kind of analysis should be shared among experts engaged in the improvement of calculation methods as policy tools and background scientific bases.

Maintenance and improvement of calculation methodologies and relevant documents takes huge amount of national resources and it seems extremely difficult for any single country to prepare more than one representative national energy calculation methodology. If the relationship between calculated and actual energy use can be improved enough, and if the operation of the calculation methodologies and compliance checking can be carried out in an appropriate way, the goal of reducing CO_2 emission due to buildings would be accomplished more efficiently.

1. Introduction

1.1 Working Group System in IEA EBC

While the Annex System is the major form of EBC's R&D activity, there have been three working groups in EBC, "Energy Efficiency in Educational Buildings" (1988-1990), "Indicators of Energy Efficiency in Cold-climate buildings" (1995-1999) and "Annex 36 Extension: The Energy Concept Adviser" (2003-2005). The first and third working groups were extensions of annexes (Annex 15 and Annex 36), and the second working group aimed to develop and test new and existing indicators of a building energy efficiency by compiling detailed data on eleven houses in seven countries and calculated twenty different indicators of energy efficiency. Therefore, it can be stated that the Working Group System in EBC has been used to strengthen output from annexes or to address any R&D topics that have a narrower scope and directly reflect the interests in EBC member countries.

1.2 Background of this Working Group

1.2.1 General

The report "Future Buildings Forum 2013" (NL-Agency (2013)) states that "the real performance of systems, especially combination of systems is currently poorly understood. Metrics to obtain information about real performance are essential for prediction of performance and the development of supporting design and decision tools*"* (p.16).

In the EBC strategic plan 2014-2019 (EBC (2013)), among five high-priority research and innovation themes, Theme #5: Real building energy use has been included with the comment "the right metrics need to be determined and applied, and that the real energy use and effectiveness of technologies for energy saving has to be based on more accurate predictions of energy performance of buildings and communities" (p.17). It also says, "building energy codes (standards) in each country and region are the most dependable methods to transform practices in the buildings sector." (p.23).

As many experts, who are engaged in the building energy performance, recognise, one of the most extensive trial to spread the energy performance certification for buildings has been tackled in European countries. As can be found in the combined reports from 29 countries, sorts of calculation methods of energy consumption have been developed and in use in some countries. (CA EPBD (2013))

In conclusion, the calculation methods of energy consumption for building energy codes are the most important and dependable metrics of building energy performance and it is one of the focal areas of the IEA EBC TCP.

1.2.2 Requirements for calculation methods

In many countries and regions, primary energy use (consumption), CO_2 emission or energy cost is used as an index representing building energy performance, which is calculated through a variety of calculation methods. Key requirements for such calculation methods are claimed to be "credibility", "discrimination" (ability to evaluate energy-efficient systems and buildings), "repeatability" and, in particular, "transparency" (Clause 14.2.3.2 of EN 15243[1]). To achieve transparency, it is necessary that all of the rationale behind the calculation and all assumptions and rationale for the input data (such as for characteristics of building equipment and components) are published. However, it seems that very few countries and regions, if any, have accomplished this idealised situation. A common challenge seems to be in the complexity and variety concerning non-residential building functions as well as technical building systems (building services). Energy calculation methods were originally developed for calculating space heating load for evaluating the effectiveness of improved building envelope and for sizing equipment. At this early stage, it was not considered crucial to convert loads into energy use nor compare energy use with that of other purposes like DHW, lighting, etc., or with energy production by PV systems. However, nowadays, the index, energy use (consumption) and the like, is commonly used to evaluate energy-saving effectiveness of various kinds of energy conservation techniques across different energy uses. The index must be able to impartially evaluate the contributions of the energy conservation techniques, and technological requirements for the index and its calculation methods must be further clarified and shared among countries and regions to learn each other.

1.2.3 Reason why we need the improvement of calculation methods

By 2030 or 2050, results produced through calculation methods will form the main guidance for design and construction practices. Reduction of energy use in each building and total amount of expected reduction of the stock as a whole can be quantified through such energy calculation methods. The effects on design and construction practice can be better guaranteed by continuing to improve the above-mentioned key technological requirements for the calculation methods. If the correlation between real and predicted energy use is assured, the implementation of calculation methods as a core part of policies can substantially contribute to the reduction of energy use and CO_2 emissions in the building sector.

Another reason is emerging HVAC technologies such as new materials, new configurations and so-called smart control strategies. They need new logics/algorisms and rationale for the energy calculation methods.

1.2.4 Information on the present international and national situations

The development of international or national standards, as the basis of the above-mentioned calculation methods, has faced challenges. While standardization is outside the scope of the EBC program, EBC's outputs however have been and shall be utilized for standardised development as the next step for EBC activities. The strategic plan 2014-2019 (EBC (2013)) states that "building energy codes (standards) in each country and region are the most dependable methods to transform practices in the buildings sector." (6.4

[1] This standard published in 2007 as "Ventilation for buildings - Calculation of room temperatures and of load and energy for buildings with room conditioning systems" has been replaced by EN 16798-13:2017, PD CEN/TR 16798-14:2017 and EN 16798-9:2017. Similar principles are described in CEN/TS 16628:2014 by using quality aspects "validation and demonstration", "relevance, sensitivity and balanced accuracy" and "transparency".

Collaboration with non-IEA bodies, p.23)

Based on the preliminary survey for this Working Group, the following observations can be made:

In CEN technical committees, a whole set of standards relating to the energy performance of buildings and the EPBD were developed and published by 2017 (see Chapter 6). Several of these standards were developed as combined EN ISO standards (EN ISO 52000 family) under the two ISO technical committees (TC163 and TC205). The complete CEN ISO set of EPB standards offers both an overall framework and a consistent methodology to assess the overall energy performance of buildings, but with several options for national choices.

In parallel with or even before the CEN and ISO standard development, many European countries and regions developed their own standards or codes. It simply takes time (1) to develop internationally harmonized calculation methods, (2) for individual countries to realize their relevance and to become committed to their further improvement, and (3) to replace national methods.

Outside Europe, numerous countries have also developed their own standards or codes and calculation methodologies. For this reason, in order to understand the state of the art of the building energy calculation methodologies, it is not sufficient to only analyse international standards and therefore it is necessary to investigate national calculation methodologies. This must be the only way by which to build an internationally common understanding of energy calculation methodologies.

The following are examples of national calculation methodologies for non-residential buildings. The information is mainly based on a survey led by MLIT, Japan, and on works undertaken by the supporting team of this Working Group. This may not represent the latest versions of calculation used, and is not represent an exhaustive list of all national calculation methodologies.

In Australia, the *Protocol for Building Energy Analysis Software* is provided by ABCB, in which minimum requirements for software and training of its users are defined. Simulation programs must use an hourly climate data file, be capable of computing the annual energy consumption in accordance with the *Verification Methods of BCA*, and provide results comparable with other similar software in accordance with *ASHRAE Standard 140*, which is based on *IEA BESTEST*.

In Denmark, *Direction 213* consists of the calculation program *Be06* and its manual, which is used to document that a building complies with the energy regulations in the Danish Building Regulations. The energy regulations came into force January 1st, 2006.

In France, the latest regulation *RT 2012* came into force on January 1st 2013. It includes three major requirements, one of which is the maximum permitted annual consumption of primary energy for HVAC, DHW and lighting. The energy calculation methods must be authorized based on the official rules called *Th-BCE 2012* developed by CSTB.

In Germany, *DIN V 18599 Energy Efficiency of Buildings* provides the methodologies for calculating the overall energy balance of buildings. The described algorithm is applicable to residential and non-residential buildings and is implemented through over 40 software tools.

In Italy, *UNI TS 11300 Energy Performance of Buildings* have been developed by Italian Thermotechnical Committee, and programs according to the standard are used for energy certifications. There are about 20 software.

In Japan, the building energy standard was revised in 2013 and 2016, and a set of calculation methods of primary energy use and envelope thermal performance were supplied jointly by NILIM and BRI. The rationale of the calculation and associated manuals are published on the website.

In Korea, EPI (Energy Performance Index) which covers equipment, criterion of envelope insulation, actual total energy consumption per unit floor area and calculated energy consumption is used for energy regulations. The tool for the energy calculation is supplied jointly by KEMCO, KICT and KIER.

In Switzerland, national standard *SIA 382/2 Air-conditioned Building – Power and Energy Needs*, provides requirements for the calculation of weighted final energy per unit floor area. In principle, any calculation method with an hourly or shorter time step can be used, but a software called *SIA TEC Tool*, which is described in *SIA 2044 Air-conditioned Building – Standard Calculation Method for the Power and Energy Requirements* has been provided[2].

In United Kingdom, the government's *Simplified Building Energy Model (SBEM) developed* by BRE and other approved software tools that are accredited for the implementation of the *National Calculation Methodology (NCM)* can be used for non-residential buildings. The general rationale of SBEM is described in *A Technical Manual for SBEM*, and the NCM is described in *National Calculation Methodology Modelling Guide*.

In the United States of America, *ANSI/ASHRAE/IES Standard 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings* has been adopted by most states as their energy code. It has both a prescriptive and performance-related provision, the Energy Cost Budget Method. Simulation programs used for code compliance or LEED performance certification shall be approved by the adopting authority and must have the ability to model factors such as hourly variations in occupancy and internal heat gains, part-load performance curves, capacity for mechanical equipment and so on. ASHRAE 90.1 requires simulation programs or the underlined simulation engines to pass the test cases defined in the ASHRAE Standard 140. Detailed algorisms and methods used to calculate the heat and moisture transfer in the buildings as well as energy use of HVAC equipment and systems are documented in the ASHRAE Fundamental Handbook and ASHRAE HVAC Systems and Equipment Handbook, as well as in EnergyPlus' Engineering Reference manual (EnergyPlus is an open-source simulation engine developed by U.S. Department of Energy's national laboratories).

Among technical building systems, HVAC systems in non-residential buildings are acknowledged to be the most complicated, where common problems regarding the calculation of energy use exist among countries. Therefore, this working group will focus on the energy calculation methodologies for HVAC systems in non-residential buildings where its state-of-the-art will be defined with analysis regarding future R&D themes.

[2] In this report, SIA 2044 published in 2011 is analyzed. However, it was revised in August 2019.

2. Participating Countries and Organizations

2.1 Participating Countries

The current participating countries are listed in Table 1.

Table 1 Country Participation

Country	Institution	Expert/Contact
Australia	Dept. of the Environment and Energy Office of Environment and Heritage, New South Wales	Stanford Harrison Nadine Wagstaff
Canada	Natural Resources Canada	Meli Stylianou
China	Tsinghua University	Yi Jiang
Italy	ENEA Politecnico di Torino	Michele Zinzi Vincenzo Corrado
Germany	Federal Institute for Research on Buildings, Urban Affairs and Spatial Development (BBSR)	Olaf Böttcher
Japan	Building Research Institute, Japan National Institute for Land & Infrastructure Management Architecture Environment Solutions	Takao Sawachi Shigeki Nishizawa Yoshihiko Akamine Masato Miyata Hiromi Habara Ken-ichi Miyajima
Netherlands	EPB-research ISSO	Jaap Hogeling Dick van Dijk
Switzerland	The Lucerne University of Applied Sciences and Arts	Gerhard Zweifel
United Kingdom	University College London	Paul Ruyssevelt Rokia Raslan
United States	Lawrence Berkley National Laboratory Pacific Northwest National Laboratory Department of Energy	Tianzhen Hong Michael I. Rosenberg Roth Amir

2.2 Organizations

The supporting team of the Working Group is organized by Building Research Institute, Japan and National Institute for Land and Infrastructure Management, Japan. The supporting team consists of six Japanese experts listed in Table 1, and they are the authors of this report, which was reviewed by other Working Group members also listed in Table 1. The Working Group Leader of this Working Group and the editor of this report is Takao Sawachi, Building Research Institute, Japan.

3. Objectives

The followings are the objectives of this WG:

- To collect world-wide technical documents on energy use calculation methodologies for HVAC systems in non-residential buildings and on their rationale including information on their validation;
- To analyse the collected documents and define methodology characteristics which are appropriate for broader utilization as best-practice examples;
- To identify the problems of modelling of core energy-saving functions of HVAC systems in their energy calculation methodologies. The problems can be future R&D themes.

4. Survey Implementation

4.1 Scope of the Survey and Implementation Stages

In this project, the calculation methods listed in Table 2 have been analyzed. In addition, some European Standards, which are the basis of European energy calculation methods, have also been analyzed.

Table 2 National Calculation Methods as Objects of Survey

Nations	Documents to be Analyzed	Names used in this report
Australia	Handbook for estimating NABERS ratings, Version 1.1	NABERS
Germany	DIN V 18599	DIN V 18599
Italy	UNI/TS 11300	UNI/TS 11300
Japan	Technical Information on Evaluation of Energy Performance based on Building Energy Conservation Standard 2016 https://www.kenken.go.jp/becc/building.html	BECS
Switzerland	SIA 2044, SIA 2024 and SIA 2028	SIA
United Kingdom	iSBEM User Guide 1 to 3 SBEM Technical Manual Non-Domestic Building Services Compliance Guide 2013 Edition National Calculation Methodology modelling guide 2013 Edition	iSBEM
United States of America	ASHRAE 90.1-2019 EnergyPlus Version 9.2.0 Documentation	ASHRAE 90.1 and EnergyPlus

The survey was implemented in two stages, the first step involved the collection of relevant documents and the implementation of preliminary analyses based on them. The results of this work are described in Chapter 6. The second step involves a more detailed analyses with a narrower focus, the results of which are described in Chapters 7 and 8.

4.2 Schedule for the Working Group

The Working Group was launched on July 1st, 2016 and will end on September 30th, 2020. This document is presented as the final draft report of the Working Group.

5. Overview of National Calculation Methods

5.1 Australia: NABERS

5.1.1 What is NABERS?

The National Australian Built Environment Rating System (NABERS) is a performance-based rating system for different space types[3] like office buildings, shopping centers and data centers. An accredited NABERS rating can only be provided after a NABERS Accredited Assessor assesses measured energy consumption data of a building. It means that NABERS is mainly based not on the calculated energy use, but on the actual energy consumption. However, energy calculations are still utilized when calculating the likely future performance of a building in design stage. This is to understand the future operational

[3] Space type is defined in NABERS as a building or part of a building.

performance of a building before it is built, and to verify it with actual energy consumption after the construction and occupation of a building. The relevant technical information of energy estimates calculated for projects in design stage is overviewed in the followings.
The method to estimate a space type's energy consumption prior to operation is outlined in the handbook for Estimating NABERS Ratings, and its contents, which are relevant to energy calculation methodologies for HVAC systems, are introduced hereafter.
The result of the energy calculation must be reviewed by a NABERS Independent Design Reviewer, and is used in a NABERS Energy Commitment Agreement, which is a contract between the NABERS National Administrator (the body responsible for administering the NABERS scheme), the Office of Environment and Heritage NSW (OEH) and the building proponent to design, build, commission and operate the buildings.
The energy calculation for NABERS is distinct from energy consumption estimates that are made for the purpose of verifying that a design complies with the National Construction Code (NCC) or Green Star design targets.

5.1.2 Requirements for energy calculations

Estimates for major energy systems and equipment (such as HVAC) must be completed using a compliant dynamic simulation software package. For small and low energy consuming systems like domestic hot water systems, a spreadsheet is acceptable. Even supplementary manual calculations are acceptable, but it must be disclosed for the Independent Design Reviewer, along with justification for use.
The person who develops the NABERS estimate (Estimator) is to confirm the ability of the proposed simulation package to model the building as part of the report delivered to the Independent Design Reviewer, and the Estimator must:

- Establish that the simulation package:
  - Support the development of a dynamic energy simulation model, assessing performance on an hourly basis for a full year
  - Are validated through ANSI/ASHRAE Standard 140, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs
- Establish that the HVAC plant and system package:
  - Represent the proposed air conditioning system and controls with reasonable accuracy
  - Allow part/low load performance, staging, minimum downturn and control strategy characteristics of plans and system components to be included.[4]
- Establish that the glazing or window model:
  - Accounts for the varying angles of incidence of direct solar radiation
  - Accounts for the total U-value and total SHGC performance
  - Calculates daylighting effects (if applicable)
- Identify any other aspects that have not been modelled accurately or where compromises have been made.

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[4] In the handbook "Handbook for estimating NABERS ratings Version 1.1", it is stated that most models make compromises in the calculation for part/low load performance, staging, minimum output and control strategy characteristics, and that the compromises can lead to significant differences between simulated energy use and actual energy use.

The modelled occupancy should reflect a realistic projection of the operating patterns of the site. This can be based on the operating patterns of the previous building(s) if such data is available. Variation in occupancy at different times of the year should be considered, for example in summer for shopping centers. Where occupancy is unknown, a default value and schedule as deemed appropriate by the Estimator can be used, and examples of the default values are given in Section 6 of the handbook. It is clearly stated that design occupant densities and heat gains for determining the size of technical building systems should not be used as these are normally intended to be maximum loads rather than typical operational loads.

The concept of "modelling margin" is used in the estimates for NABERS. As the modelling is conducted in early design stages prior to construction and operation, various factors may prevent the building from reaching the targeted rating. These unforeseen circumstances can be accounted for by modellers using the modelling margin. A specific value for the modelling margin is not recommended by NABERS, but Estimators are required to implement and justify an appropriate modelling margin for each project. The modelling margins apply to the total estimated energy as follows:

$$Total\ estimated\ energy\ with\ margin = total\ estimated\ energy\ \times \left(1 + \frac{margin\ in\ \%}{100}\right) \quad (1)$$

Another concept characterizing NABERS is "off-axis model", which is a model that represents the space type (building) after factoring in a minimum of four off-axis scenario. The off-axis scenario is defined as a scenario representing operational change(s), such as how a building is occupied, controlled or maintained. The off-axis scenarios are designed to test a building's ability to reach the targeted star rating with modelled changes to assumptions and inputs.
The model before applied the off-axis scenarios is called "base case model", which needs to be calculated as the total estimated energy with the above-mentioned modelling margin. In the off-axis scenarios, the base case model should be varied in order to explore the building's resilience to real-world performance risks, such as:

- Incomplete specification or substitution of equipment
- Incomplete specification or in-use change of controls
- Commissioning errors or omissions of commissioning
- Changes or uncertainty in occupancy and other operating patterns
- Comfort or equipment capacity problems
- Challenges around the use of sub-meters to include or exclude energy from the rating[5]

The scenarios should be chosen to test the impact of parameters that are the least well defined or have the potential for the most impact for a specific building. Potential parameters for the off-axis scenarios are exemplified in the handbook, and some of them are summarized in the followings.

- HVAC controls failure
  Potential scenarios include:
  - Increased overnight infiltration rates, for example due to failure to switch off tenant kitchen exhaust fans overnight

[5] This item is relevant to the main part of NABERS ratings based on measured energy consumption.

- Failed CO_2 sensors leading to the system continually operating at design ventilation rates rather than ramping down
- Tighter control bands on temperature control, for example no deadband and heating and cooling proportional bands only 0.5°C each

- HVAC loads

  Almost all buildings contain areas with atypical loads that can cause, for example, cooling demand in the middle of winter. Specific items may include:
  - Variation in temperature set point
  - Lower or higher occupant density or other internal loads
  - Failed lighting controls
  - Chiller energy consumption at low level base loads
  - Fan turndown capability, and how this affects the minimum area to be served in response to an after-hours request
- Infiltration

  Sensitivity of the model should be tested to a range of infiltration scenarios, in recognition of the difficulty of infiltration to predict. This is due to the possibility of infiltration increasing if façade construction is poor, doors are left open or exhaust fans are left running longer than expected.

5.1.3 Requirements for Estimator's report

A report must be provided by Estimators to the selected Independent Design Reviewer with the following contents:

- Input data and assumptions for base case and off-axis models
- Simulation results for base case and off-axis models
- Metering description
- Risk assessment

In addition to the above four items, a compliance checklist and a disclaimer must be included in the report. The simulation results must be presented and include the following information:

- The NABERS Energy Stars (without Greenpower only)
- The performance level in MJ/year and kg CO_2-e/year
- The intensity values (MJ/year/m^2 and CO_2-e/year/m^2)

For the sake of collecting energy consumption data successfully for the NABERS Energy rating, a full description of the metering arrangements assumed or required must be provided in the report. Any risks around metering should be identified, and the risk associated with sub-metering should also be noted. This analysis on the way of metering energy consumption in addition to the simulation results characterizes the NABERS estimate, since a good preparation of the plan for metering prior to construction is critical in order to be successful in collecting meaningful data to be used for evaluating the building energy efficiencies.

The Estimator must summarize any risk factors that might prevent the project from achieving its estimated rating. These risks must include at a minimum:

- Difference between the specification documents and model
- Building design
- Material specified

- Equipment specified
- Risk as derived from the off-axis scenarios
- Risk associated with changes made after the design phase
- Risk associated with commissioning and controls when in operation
- Any other risks identified through assumptions and inputs used when estimating the rating

For each risk, the Estimator must describe the potential impact as well as how the risk has been or might be mitigated.

5.2 Germany: DIN V 18599

5.2.1 Structure of DIN V 18599

DIN V 18599 is the German standard for the calculation of primary and final energy demand[6] for heating, cooling, ventilation, domestic hot water and lighting in buildings. The development of the standard commenced in 2002 by the committee formed by the German Federal Ministry of Transport, Building and Urban Affairs in response to European Directive 2002/91/EC on the energy performance of buildings (EPBD). The first version of DIN V 18599 was published in 2005.

DIN V 18599 consists of eleven chapters listed in Table 3. Among these, Part 1-3, 7 and 10-11 are especially relevant to HVAC energy calculation for non-residential buildings.

In DIN V 18599-1, "net energy demand", "final energy demand" and "primary energy demend" are defined as follows:

Net energy demand is a generic term for useful heat demand, useful cold demand, useful energy demand for domestic hot water and useful energy demand for lighting. Final energy demand is calculated amount of energy provided to the plant engineering (heating system, HVAC system, water heating system, lighting system) to ensure the specified indoor temperature, warming of the hot water and the desired lighting quality throughout the year. Primary energy is calculated amount of energy, which in addition to the energy content of the necessary fuel and the auxiliary energy for the system engineering also includes the amounts of energy that arises through upstream process chains outside the building in the extraction, conversion and distribution of each used fuels or substances.

In the DIN V 18599 calculation, monthly average outdoor temperature, monthly average outdoor wind speed and annual radiation intensities are used. The climatic data of one location, which is Potsdam, as described in Part 10: Boundary conditions of use, climatic data, is used for the energy certification. Although climatic data for 15 reference regions in Germany can be used in standard design practice, the common climatic data is used since the difference between climatic conditions is not extreme among German regions.

[6] In DIN V 18599, "energy demand" is used instead of "energy use", because in Germen language "energy use" usually means a measured value not a calculated value of energy consumed in buildings. In 5.2 of this report, "energy demand" is used instead of "energy use".

Table 3 List of Parts in DIN V 18599 (as of October 2017), Energetic assessment of buildings - Calculation of net (useful), final and primary energy demands for heating, cooling, ventilation, domestic hot water and lighting

Part 1: General balancing procedures, terms, zoning and evaluation of energy sources
Part 2: Net energy demand for heating and cooling of building zones
Part 3: Net energy demand for air conditioning
Part 4: Net and final energy demand for lighting
Part 5: Final energy demand of heating systems
Part 6: Final energy demand of ventilation systems and air heating systems for residential buildings
Part 7: Final energy demand of air-handling and air-conditioning systems for non-residential buildings
Part 8: Net and final energy demand of domestic hot water systems
Part 9: Final and primary energy demand of power generation plants
Part 10: Boundary conditions of use, climatic data
Part 11: Building automation

5.2.2 Heating and Cooling Demand Calculation Zoning

In chapter 6 entitled "Zoning of the building" of DIN V 18599-1: 2016, the rules of how zones shall be defined for buildings to be calculated of their energy demand are prescribed.
A building is divided into zones. A zone is the basic unit for the calculations for not only HVAC but also for lighting and domestic hot water. It comprises the section of the floor area or part of a building with rooms or spaces that are characterized by uniform boundary conditions of use, the same mode of conditioning, and uniform zoning criteria. Uniform zoning criteria means that spaces/rooms with the same conditioning requirements (for thermal and lighting aspects) and the same type of HVAC system are zoned together. For example, two adjacent rooms serviced by HVAC systems with different controls for supply air volume should be divided into different zones, even if they have the same boundary condition of use and the same specification of façade, such as for glass area ratio, insulation and solar shading.
Following initial zoning, small zones may be merged into other zones, if they account for up to 5% of the total floor area of the building and have similar technical systems (for space heating, cooling, ventilation and lighting) and internal loads. In addition, very small zones up to 1% of the total floor area of the building may be merged into other zones, even if the type of technical system differs.

5.1.3 Net Energy Demand and Final Energy Demand Calculation for Heating/Cooling, Lighting and Domestic Hot Water

The following steps 1) to 23) describe the process for calculating energy demand for space heating and cooling.

In the first five steps 1) to 5), zones are determined with conditions of use, and input data for each zone is compiled. Energy demands for lighting, mechanical ventilation and appliances (as a part of conditions of use) are calculated as heat gains, and heat emission from occupants is calculated:

1) Determination of the boundary conditions for use and, if necessary, zoning of the building according to types of use, building envelope, system technology including lighting according to the specifications in DIN V 18599-10.
2) Compilation of the necessary input data for balancing the building zones (areas, building physical parameters, system technical parameters, also supply air temperature and air exchange for certain ventilation systems according to DIN V 18599-10 or DIN V 18599-3).
3) Determination of the net energy demand and final energy demand for the lighting as well as the heat sources in the zone by the lighting according to DIN V 18599-4.
4) Determination of the heat gains/losses by mechanical ventilation in the zone according to DIN V 18599-6 and DIN V 18599-7.
5) Determination of the heat gains/losses from people, appliances etc. according to DIN V 18599-2.

In the steps 6) to 11), energy demand for heating and cooling of each zone us calculated:
6) Rough balancing of the net heating/cooling demand of the zone (separated for days of use and days of non-use) according to DIN V 18599-2, taking into account the already known heat gains/losses.
7) Preliminary allocation of the balanced net energy demand to the supply systems (HVAC system according to DIN V 18599-3 and DIN V 18599-7, heating and cooling system according to DIN V 18599-5 and DIN V 18599- 7).
8) Determination of the heat gains through the heating in the zone (distribution, storage, possibly generation in the zone) according to DIN V 18599-5 on the basis of the approximate net heating demand.
9) Determination of the heat gains/losses through the cooling in the zone (distribution, storage, if necessary generation in the zone) according to DIN V 18599-7 based on the approximate net cooling demand.
10) Determination of the heat gains through the domestic hot water preparation (distribution, storage, possibly generation in the zone) according to DIN V 18599-8.
11) Balancing of the net heating/cooling demand of the zone (net energy demand, separated for days of use and days of non-use) according to DIN V 18599-2.

The iteration with steps 7) to 11) is to be repeated until two successive results for the net heat demand and the net cooling demand do not differ by more than 0.1% from each other differ, but no more than 10 times. The resulting discrepancy between the last two iteration steps must be specified in the calculation.

In the steps 12) and 13), energy demand for each HVAC system and heating system is calculated:
12) Determination of the net energy demand for air conditioning and, if necessary, balancing of the net cooling demand of the zones (VAV systems) according to DIN V 18599-3.
13) Final allocation of the balanced net energy demand to the supply systems (HVAC system according to DIN V 18599-3 and DIN V 18599-7, heating and cooling system according to DIN V 18599-5 and DIN V 18599- 7).

In the steps 14) to 20) except for 18) (for domestic hot water), net energy demand (for space heating and cooling) supplied by each heat generator is calculated. In the step 19), the losses calculated in the step 14) and 16) for heating are added to the net energy demand (for heating) of the supply system, which has been calculated in the step 13). In the step 20), the losses calculated in the steps 15) and 17) for cooling are added to the net energy demand (for cooling) of the supply system, which has been calculated in the step 13):

14) Determination of the losses of the transfer, distribution and storage for the heating (net heating output of the generator) according to DIN V 18599-5.
15) Determination of the losses for air transfer and distribution systems according to DIN V 18599-7 and DIN V 18599-6.
16) Determination of the losses of the transfer, distribution and storage for the heat supply of an air conditioning system (net heat output of the generator) according to DIN V 18599-7.
17) Determination of the losses of the transfer, distribution and storage for the cooling supply (net cooling output of the generator) according to DIN V 18599-7.
18) Determination of the losses of the transfer, distribution and storage for the domestic hot water preparation (net heat output of the producer) according to DIN V 18599-8.
19) Distribution of the necessary net heating output from all producers to the different generation systems in accordance with DIN V 18599-5.
20) Distribution of the necessary net cooling output from all generators to the different generation systems in accordance with DIN V 18599-7.

In the steps 21) to 23), losses during generation of coolth, steam ad heat are calculated, respectively:
21) Determination of the losses when generating cold medium according to DIN V 18599-7.
22) Determination of the losses when generating steam according to DIN V 18599-7.
23) Determination of the losses during the generation of heat according to DIN V 18599-5 (heat generator), according to DIN V 18599-8 (hot water heat generator), according to DIN V 18599-9 (Combined Heat and Power, etc.) and if necessary according to DIN V 18599-7 (waste heat refrigeration machine).

Primary energy demand is calculated in the steps 24) to 26):
24) Compilation of the determined auxiliary energy demand (e.g. expenditure for air transport according to DIN V 18599-3 and DIN V 18599-6).
25) Compilation of the final energy demand for energy carriers according to DIN V 18599-1.
26) Primary energy demand assessment according to DIN V 18599-1.

The supply air flow volume of HVAC systems is estimated while taking into account whether their supply air flow volume is (a) constant for outdoor air supply requirement, (b) regulated according to a schedule, (c) constant for covering the maximum cooling need, (d) variable according to cooling need, or (e) variable according to outdoor air supply requirement.
The electrical fan power is calculated as a quotient of the monthly average air flow volume multiplied by the pressure drop across the supply (or extract) duct at design air flow volume to the overall efficiency of the fan and the motor. The default values of the overall efficiency of the fan system are given, but improved efficiency can be accepted if verified according to EN 16798-3. The reduction of the electrical power due to the variable air volume control is evaluated by, presumably, dividing the whole supply duct network into two sections, namely one with constant air flow resistance and another with variable resistance by variable air volume units (see 5.2.5).
The energy demand for HVAC systems for heating, cooling, humidification and dehumidification is calculated by using monthly specific energy demands for those purposes, which is defined as the quotient of energy need to the monthly averaged air flow volume. Specific energy need are given for 46 categories of HVAC systems.

The electric power of the pumps for transporting hot/cold water and cooling water is calculated by estimating the pressure losses (pipe length, pressure drop in kPa/m and due to components), the volume flow rate, pump operating time, existence of pump control and pump efficiency.
The energy demand of the refrigerator (cold generator) is calculated by dividing the annual energy output of the generator by EER (rated energy efficiency) and by PLV_{av} (mean part load value). EER values are given as default values for each type of generator and conditions such as water inlet and outlet temperatures. PLV_{av} values are also given as default values for each combination of types of generator and conditions of space use.

5.2.4 Final Energy Demand Calculation of Refrigerators

The final energy demand (energy use) for refrigeration is calculated on the basis of specific characteristic values which depend on both the technology used and the usage of the system. These characteristic values are prepared on the basis of hourly values of energy need and given as tables in Annex A of DIN V 18599-7. The characteristic values are calculated by using the climatic conditions of the representative station in Potsdam.
In the following, energy calculation methods for compression refrigeration unit, air-cooled room air-conditioning system and absorption chiller are overviewed:

<u>Energy Demand for Compression Refrigeration Unit</u>
Energy demand of cold-vapor compression refrigeration units is calculated on the basis of the rated energy efficiency ratio of cooling (EER) and the mean part load value (PLV_{av}), using the following equation.

$$\mathrm{EER} \cdot \mathrm{PLV_{av}} = \mathrm{SEER} = \frac{Q_{C,outg,a}}{Q_{C,f,electr}} \qquad (2)$$

$$\mathrm{EER} = \mathrm{EER_B} \cdot f_{C,B} \qquad (3)$$

where
EER is the rated energy efficiency ratio of cooling in kW/kW;
PLV_{av} is the mean part load value;
SEER is the seasonal energy efficiency ratio in kWh/kWh;
$Q_{C,outg,a}$ is the annual refrigeration energy output in kWh;
$Q_{C,f,electr}$ is the final energy demand (energy use) of the compression refrigeration unit in kWh;
EER_B is the rated energy efficiency ratio of cooling with the age factor $f_{C,B} = 1$;
$f_{C,B}$ is the age factor for the chiller.

The mean part load value (PLV_{av}) accounts for the real partial load characteristics of the refrigeration unit, the effect of the external air temperature or cooling water and the effect of the heat exchangers which may be incorrectly dimensioned in partial load conditions.
For water-cooled compressor-type refrigeration units, air-cooled compressor-type chillers and air-cooled room air-conditioning systems, default values of EER_B are given. For example, air-cooled compression-type chillers of the types listed in Table 4 are considered in the characteristic value method.
The rated energy efficiency ratio (EER_B) of the air-cooled compression-type chillers is strongly product-dependent and it is generally not easy to maintain high reliability of test results without involvement by a

third party. For the characteristic value method, EER_B is taken as the default value in Table 5. The values given are for 33 °C outdoor air temperature (22 °C wet bulb temperature) with a pollution factor of 0.044 m^2K/kW. If the compressor type is not known, the EER default value can be determined based on the specified normal power ranges.

Table 4 Types of partial load control of air-cooled compressor-type chillers evaluated by the characteristic value method

(A)	Piston / scroll compressor with two-point control clocking with buffer storage (on / off operation)
(B)	Piston / scroll compressor multi-stage switchable (at least four switching stages as compressor group)
(C)	Screw compressor with spool control
(D)	Screw compressor with inverter control
(E)	Turbo compressor with inverter control
(F)	Digital scroll compressor
The data also applies to air-cooled split-type compression refrigerators.	

Table 5 Default value of the rated energy efficiency ratio EER_B for air-cooled compression refrigerators

Refrigerant	Chilled water outlet temperature °C	Average evaporation temperature °C	Default value of the rated energy efficiency ratio, EER_B Normal power range		
			Piston / scroll compressor 10kW-1500kW	Screw compressor 200kW-2000kW	Turbo compressor 500kW-8000kW
R134a	6	0	2.7	2.9	3.3
	14	8	3.3	3.6	4.2
R1234ze	6	0	-	2.9	3.3
	14	8	-	3.6	4.2
R290	6	0	2.6	2.8	-
	14	8	3.2	3.5	-
R407C	6	0	2.5	2.6	
	14	8	3.1	3.3	
R410A	6	0	2.3	-	
	14	8	3.0	-	
R717	6	0	-	3.1	
	14	8	-	3.8	
R22	6	0	2.8	3.0	
	14	8	3.4	3.7	
NOTE 1 For air cooled refrigerated chillers with dry condenser the following applies: $EER_{Split} = EER \cdot 0.95$ NOTE 2 For air-cooled HVAC-integrated compression refrigerators with condensers in exhaust air: $EER_{EHA} = EER \cdot 0.83$					

The mean annual partial load factors PLV_{av} are given in Annex A of DIN V 18599-7, and depend on the use of the building for the refrigeration systems under consideration. The types of use correspond to the usage profiles defined in DIN V 18599-10, in which 43 types of room usage are determined for schedule of room usage, operating hours of HVAC and heating systems, conditions of lighting, temperature setting, moisture requirement, outdoor air requirement and internal heat gains from occupants and appliances. In the case of use deviation, a usage type must be selected which corresponds to the planned usage profile. Otherwise, the partial load values for the individual office (type of use 1) are to be expected. Only the first page of the tables for the PLV_{av} is shown in Table 6.

Table 6 Partial load factors (PLV_{av}) for water-cooled and air-cooled compressor type cold generators (room usage: single office, group office, open-plan office, meeting, main hall, WC, other common room, secondary area without lounge, warehouse)

Compressor-type, water-cooled	Operating mode: Room cooling / HVAC cooling			Cooling water into refrigeration unit: Constant				Cooling water into refrigeration unit: Variable			
				Evaporative recooler power controlled		Dry recooler power controlled		Evaporative recooler power controlled		Dry recooler power controlled	
				PLV_{av} (-)	$f_{R,VK}$ (-)	PLV_{av} (-)	$f_{R,TK}$ (-)	PLV_{av} (-)	$f_{R,VK}$ (-)	PLV_{av} (-)	$f_{R,TK}$ (-)
(1)	room cooling			0.94	0.14	0.92	0.10				
	HVAC cooling	Humidity requirement: none / with tolerance	No heat recovery	0.97	0.11	0.97	0.09				
			With heat recovery	0.95	0.12	0.95	0.10				
		Humidity requirement without tolerance	No heat recovery/only heat	0.94	0.12	0.94	0.09				
			Heat recovery: heat and moisture	0.93	0.12	0.93	0.09				
(2)	room cooling			1.32	0.13	1.26	0.09	1.54	0.45	1.73	0.69
	HVAC cooling	Humidity requirement: none / with tolerance	No heat recovery	1.39	0.10	1.33	0.09	1.63	0.44	1.78	0.93
			With heat recovery	1.37	0.12	1.31	0.09	1.59	0.47	1.75	0.90
		Humidity requirement without tolerance	No heat recovery/only heat	1.36	0.11	1.30	0.09	1.58	0.44	1.76	0.76
			Heat recovery: heat and moisture	1.34	0.12	1.28	0.09	1.57	0.45	1.74	0.76
(3)	room cooling			0.80	0.14	0.77	0.10	0.94	0.48	1.05	0.71
	HVAC cooling	Humidity requirement: none / with tolerance	No heat recovery	0.72	0.11	0.69	0.09	0.84	0.48	0.92	0.94
			With heat recovery	0.75	0.13	0.72	0.10	0.87	0.50	0.96	0.91
		Humidity requirement without tolerance	No heat recovery/only heat	0.73	0.12	0.70	0.09	0.86	0.48	0.95	0.78
			Heat recovery: heat and moisture	0.74	0.13	0.71	0.09	0.87	0.49	0.96	0.78

(Continuation of Table 6)

Compressor type, air-cooled	Operating mode: Room cooling / HVAC cooling			Outside-air-operated	Extraction mode	
					HVAC without evaporative cooling	HVAC with evaporative cooling
				PLV_{av} (-)	$PLV_{av,exh}$ (-)	$PLV_{av,exh,ic}$ (-)
(A)	room cooling			1.28	-	-
	HVAC cooling	Humidity requirement: none / with tolerance	No heat recovery	1.15	1.15	1.15
			With heat recovery	1.16	1.14	1.24
		Humidity requirement without tolerance	No heat recovery/ only heat	1.18	1.14	1.28
			Heat recovery: heat and moisture	1.18	1.16	1.16
(B)	room cooling			1.40	-	-
	HVAC cooling	Humidity requirement: none / with tolerance	No heat recovery	1.27	1.27	1.27
			With heat recovery	1.28	1.26	1.33
		Humidity requirement without tolerance	No heat recovery/ only heat	1.30	1.26	1.38
			Heat recovery: heat and moisture	1.31	1.28	1.28
(C)	room cooling			1.08	-	-
	HVAC cooling	Humidity requirement: none / with tolerance	No heat recovery	0.83	-	-
			With heat recovery	0.89	-	-
		Humidity requirement without tolerance	No heat recovery/ only heat	0.90	-	-
			Heat recovery: heat and moisture	0.92	-	-

Energy Demand for Air-cooled Room Air-conditioning System

Room air conditioners ≤ 12 kW are subject to an energy labeling obligation under Regulation (EU) No 626/2011 since 2013 and must comply with minimum efficiency values under Regulation (EU) No 206/2012. For room air conditioners covered by these regulations, the annual energy figure given on the energy label may be used directly in SEER cooling mode as part of the characteristic value procedure.

For room air conditioners manufactured up to 2012 and indoor climate systems> 12 kW, the types of compressor or control system listed in Table 7, are considered as part of the characteristic value method.

The rated cooling efficiency for indoor air conditioning systems (VRF) > 12 kW can be taken as the default value from Table 7. The values stated apply to 33 °C outdoor air temperature (21 °C wet bulb temperature) and 26 °C room temperature (19 °C wet bulb temperature).

Table 7 The rated energy efficiency ratio, EER_B for air-cooled air conditioning systems>12 kW

Indoor air conditioning systems > 12 kW air-cooled, rated energy efficiency ratio, EER		
Conditioning system	EER_B	Type of partial load regulation
VRF systems with variable refrigerant mass flow	3.4	at least one parallel compressor inverter-regulated (Continuous regulation for multi-zone systems Inverter-regulated / clocking, with electronic expansion valve)

Energy Demand for Absorption Chiller

The energy calculation of absorption chillers is based on the heat ratio ζ and a mean partial load factor PLV_{av} according to equation:

$$\zeta \cdot PLV_{av} = \zeta_{av} = \frac{Q_{C,outg,a}}{Q_{C,f}} \quad (4)$$

where

ζ is the rated heat ratio in kW/kW;

PLV_{av} is the mean part load value;

ζ_{av} is the mean annual heat ratio in kWh/kWh;

$Q_{C,outg,a}$ is the annual refrigeration energy output in kWh;

$Q_{C,f}$ is the heat supply to the absorption chiller in kWh;

The rated heat ratio ζ represents the ratio of the rated cooling capacity to the supplied heat under design conditions. The coefficient of performance of an absorption chiller varies under partial load conditions. These variable conditions are represented by the technology-dependent average partial load factor PLV_{av}. It takes into account the real partial load behavior of the chiller, the influence of the cooling water temperature and the influence of the over-dimensioned heat exchangers in the partial load case.

The rated heat ratio ζ is subject strongly product-dependent and it is generally not easy to maintain high reliability of test results without involvement by a third party. For the characteristic value method, the rated heat ratio ζ can be taken as a default value from the following table. Unfilled columns mean impermissible system boundary conditions. The ζ values are valid for the specified system temperatures with a pollution factor of 0.044 m^2K/kW. The cooling water temperature level should be selected according to the type of re-cooling. For the dry cooler, the cooling water inlet / outlet temperature at 40°C / 45°C (glycol content 30%) must be set at 27°C / 33°C for the evaporative re-cooler.

Table 8 Rated heat ratio ζ, partial load factors PLV and average utilization factors Re-cooling $f_{R,av}$ for exhaust and adsorption chillers (part of the original table in DIN V 18599-7)

Heating medium inlet/outlet temperature °C	Cooling water inlet/outlet temperature °C	Chilled water outlet temperature °C	Rated heat ratio, ζ			
			>=200kW	< 200kW		
			H_2O-LiBr	H_2O-LiBr	NH_3/H_2O	H_2O/Silica zeolite adsorption
70/60	Refer to the original standard.					
80/70						
90/75						
110/95						
130/110	27/33	6	0.71	-	-	-
		12	0.72	-	-	-
		16	0.73	-	-	-
	40/45	6	0.70	-	-	-
		12	0.71	-	-	-
		16	0.72	-	-	-
Two-stage 170/155 steam 0.6 to 0.8 MPa	27/33	6	1.20	1.20	-	-
		12	1.25	1.25	-	-
		16	1.30	1.30	-	-
Part load factor for room cooling and HVAC Cooling		PLV_{av}	0.95	0.95	0.95	0.95
Usage factor recooling		$f_{R,av}$	0.65	0.65	0.65	0.65
Specific internal auxiliary energy input for pumps		$P_{el,C,therm}$ in W_{el}/kW_{cold}	15	15	40	0

5.2.5 Energy Demand Calculation for HVAC System Air Transportation

Default values for energy efficiency of fans are given as shown in Table 9.

Table 9 Default values for fans

Fans SFP 4 (see DIN EN 16798-3)	Specific Fan Power, P_{SFP} kW/($m^3 \cdot s^{-1}$)	Total pressure increase, Δp_{tot} Pa at total efficiency η_{tot} = 60% of the fan $P_{SFP} = \Delta p_{tot} / \eta_{tot}$
Exhaust fans	1250	750
Supply fans with heating	1600	960
Supply fans (partial) air conditioning systems	2000	1200

When better values than specified in the Table are used for the energy calculation, the SFP value according to DIN EN 16798-3 must be verified. For variable volume flow systems, the quotient of the constant pressure and total pressure fraction f_p is calculated for the calculation of the energy air transport according to DIN V 18599-3: 2016-10, 6.2 according to Table 10.

Table 10 Default values for constant pressure component

Pressure control VVS system	Pressure ratio, f_P
Volume flow control with constant admission (outlet) pressure	0.4
VAV systems with temperature and/or demand-dependent volume flow control with variable pre-pressure (corresponds to a continuous automated hydraulic balancing of supply and exhaust air line - volume flow controller in the negative point is almost fully open in the control range)	0.25

Relevant descriptions for air transportation are in chapter 6 of DIN V 18599-3. The electric fan power for systems with constant volume flow is calculated, in principle, according to the following equations:

$$P_{v,SUP,mth} = \frac{V_{SUP} \Delta P^{*}_{SUP}}{\eta_{SUP}} \tag{5}$$

$$P_{v,ETA,mth} = \frac{V_{ETA} \Delta P^{*}_{ETA}}{\eta_{ETA}} \tag{6}$$

where

$P_{v,SUP,mth}$ and $P_{v,ETA,mth}$ are the electric power,
η_{SUP} and η_{ETA} are the average overall efficiency of the fan, transmission system, motor, speed control,
V_{SUP} and V_{ETA} are the air volume flow in partial load case, in m^3/h, and
ΔP^{*}_{SUP} and ΔP^{*}_{ETA} are the total pressure loss of the duct network at design air volume flow, in Pa, for the supply and exhaust fans, respectively,

For variable air volume systems, the following calculation method is applied. The volume flows of each room or each building zone are changed via decentralized volume flow controllers (throttle control) and whose central supply and exhaust fans are regulated by means of speed control with regard to a constant duct pressure.
In this case, as shown in Figure 1 (arranged from the original figure no.3 in section 6.2), the duct system is to be divided into
- A section with constant resistances or variable pressure losses,
- A section with variable resistances or constant pressure losses.
The position of the sections is determined by the position of the pressure sensor in the duct system, which is referred for fan speed control.

For calculating energy use of the fan, the following parameters must be known:
- the design volume flow of the duct system $V_{SUP}*$;
- the design pressure loss of the whole duct network $\Delta p*$;
- the constant pressure loss of the partial duct network with variable resistance Δp_{konst};
- the average overall efficiency of the system fan - transmission - engine - speed control.
The electric power of the fans $P_{V,SUP}$ is given at any partial load flow rate, V_{SUP}:

$$P_{V,SUP} = \frac{V_{SUP} \cdot \Delta p^{*} \cdot f_{p,SUP}}{\eta_{SUP}} + \frac{V^{3}_{SUP} \cdot \Delta p^{*} \cdot (1 - f_{p,SUP})}{\eta_{SUP} V^{*2}_{SUP}} \tag{7}$$

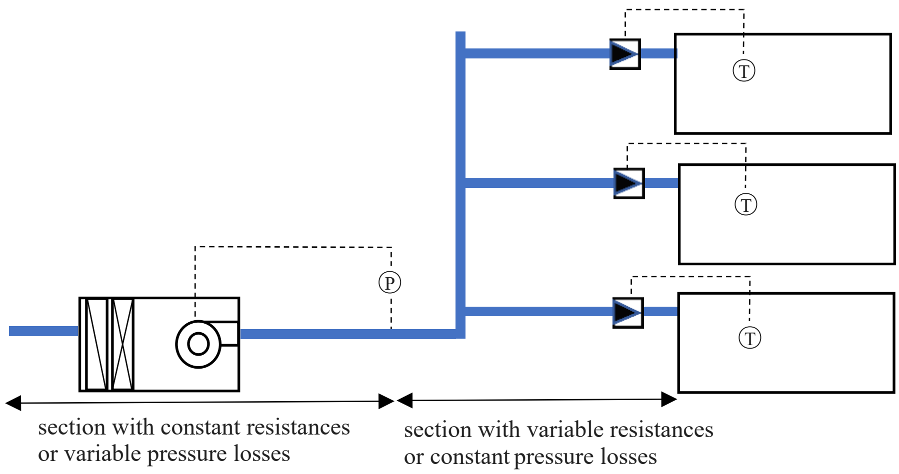


Figure 1 Subsections with constant and variable resistances of a duct system

In the calculation of pump energy for cold water transportation, the input parameters listed in Table 11 are taken into consideration.

Table 11 Main parameters for calculating the energy use of pumps for cold water and cooling water transportation

Parameters	Cold water	Cooling water
Refrigeration	Rated capacity of refrigeration system	Rated capacity of refrigeration system
		Coefficient of performance or heat ratio
Cooling control	Distribution of total output on chillers and partial shutdown of individual evaporators	Distribution of total output on chillers and partial shutdown of individual condensers
	Control of the chiller in partial load condition	Control of the chiller in partial load condition
	Use of cold storage systems	Control strategy of refrigeration system, cooling tower fan and pump
	Minimum amount of water for evaporator	Minimum amount of water for condenser
Fluid conveyance	Temperature difference input/output	Temperature difference input/output
	Pressure losses -longest water paths -pipe network cross sections -fittings, heat exchangers -hydraulic balancing	Pressure losses -longest water paths -pipe network cross sections -fittings, heat exchangers -type (open or closed)
	Brine (water, glycol, etc.)	Heat transfer media (water, glycol, etc.)
Pump selection	Design quality [a)]	Design quality
	Pump type and efficiency	Pump type and efficiency
	Use of controlled and uncontrolled pumps	Use of controlled and uncontrolled pumps
	Control mode of pumps	Control mode of pumps
Structure of distribution circuit [b)]	Location of chiller to distribution circuit	Location of chiller to cooling tower
	Single-circuit or dual-circuit system (with primary and secondary circuits)	-
	Distribution of user circuits corresponding to the cooling demand (cooling section or zone control)	-
	Carrying out a hydraulic adjustment	-
	Fluid mixing and overflows in the distribution circuit	-
Operation time / load profiles	Cooling hours of the building	Operation hours of the refrigeration system
	Pump shut-down when no cooling need -by section: HVAC and building zone -by time: seasonal as well as night and weekend shut-down or reduction of power [c)]	Pump shut-down when no cooling need -via chiller -use of cooling tower for free cooling
	Integration into the building automation	Integration into the building automation
Power control in distribution circuit	Mass flow control with -two-way throttle valves or -three-way diverter valves or -regulated pump	Mass flow control with -two-way throttle valves or -regulated pump
	Temperature control with three-way mixing valves	Temperature control with three-way mixing valves
	Interaction between consumers and pump	Interaction between cooling tower and pump
Other auxiliary energy	Pumps for -air humidification -indirect evaporative cooling	Circulation spray pumps
	Pumps for integrated fluid circulation in heat recovery systems	Frost-protection heating
	Systems for pressure maintenance and degassing systems	Water treatment and dosing pumps
	Condensate pumps	-
	Electromotive and electro-thermal valves	-

a) Deviation of the operating point from the design point
b) The system design influences the required pump capacity, the operating time and the possibility of pump control
c) Intermittent operation

Among the items for the structure of distribution circuit in Table 11, “Carrying out a hydraulic adjustment” is included. For this aspect, a correction factor for hydraulic adjustment (f_{Abgl}) is applied. If the hydraulic adjustment is carried out, f_{Abgl}=1.0, otherwise f_{Abgl}=1.25. The effect of “adjustment” of any part of HVAC systems is rarely considered in national energy calculation tools, and this part of DIN V 18599 is a quite meaningful example to take “adjustment” into consideration in the calculation methodologies. It is quite often that a pump with much larger capacity than design requirement, and the adjustment of discharge pressure after the pump by using inverters can contribute to the reduction of power consumption.

The pump energy use is calculated by using the following coefficient for the pumps, themselves, and the control method for the pumps.

$$e_{d,l} = f_e \cdot (C_{p1} + C_{p2} \cdot \beta_{d,l}^{-1}) \qquad (8)$$

where

$e_{d,l}$ is the number of efforts for the cold water distribution,

f_e is the efficiency factor of the pumps,

C_{p1} , C_{p2} are the constants to take into account the power adjustment of the pumps and

$\beta_{d,l}$ is the average ratio of the cooling load to the cooling capacity of the distribution system.

C_{p1} , C_{p2} are given for uncontrolled and controlled operations as in Table 12.

Table 12 Values for C_{p1} , C_{p2} depending on the operating mode of the pumps

Pump operation	uncontrolled	controlled
C_{p1}	0.25	0.85
C_{p2}	0.75	0.15

5.2.6 Calculation of Energy Demand for Heat Generators for Space Heating

The calculation method for heat generator energy demand for space heating is described in 6.5.3 (motor-driven heat pumps), 6.5.4 (boilers) and 6.5.5 (sorption gas heat pumps) of DIN V 18599-5.

As for the motor-driven heat pumps, the following factors are taken into account:

- Type of heat pumps (air-water, brine-water, water-water, direct condensation, etc.);
- System configuration (priority switching of domestic hot water heating before space heating, combined operation with simultaneous domestic hot water and room heating);
- Operation in bivalent operation combined with boilers depending on outdoor temperature;
- Running time for space heating, domestic hot water heating and combined operation;
- Effects of variation of source and sink temperature on the capacity and COP;
- Effects of part-load operation of single-stage, multi-stage and continuously controlled heat pumps on the COP;
- Required auxiliary power for operation of the heat pump, which is not taken into account in test conditions;
- System losses due to built-in storage.

Heating energy demand for heat pumps is calculated following DIN V 18599-5, while energy demand for cooling is calculated following DIN V 18599-7 in a quite different way.

The basic procedure for calculating energy demand for heating is divided into the following steps:

1. Evaluation of source temperature (determination of outdoor temperature classes and their heating degree hours);
2. Reduction of the heat output by the heat pump;
3. Allocation of the heat output to the temperature classes;
4. Correction of the source (e.g. outdoor temperature) and sink (e.g. room temperature) temperatures for adjusting test results of the heat pump;
5. Consideration of the partial load behavior of the heat pump;
6. Calculation of running times;
7. Calculation of the actual heat output, auxiliary energy use and total energy demand.

Necessary heat pump monthly heat outputs ($Q_{h,\,outg}$) are divided into temperature class i, which are defined as shown in the following table commonly used for all areas in Germany, by using the following equation:

$$Q_{h,outg,i} = Q_{h,outg} \cdot \left(\frac{DH_{TK,i,mth}}{HDH_{t,mth}} - k\right) \qquad (9)$$

where $Q_{h,outg,i}$ is necessary heat pump heat output for the temperature class i in the month mth,
$DH_{TK,i,mth}$ is the degree hours of the temperature class i in the month mth,
$HDH_{t,mth}$ is the total degree hours of all temperature classes in the month mth and
k is the coverage of the second heat generator for bivalent operation.

Table 13 Default values for the monthly hours and the degree hours in the individual temperature classes, which are divided into the test points according to EN 14511-2

temperature class	W-7	W2	W7	W20	Monthly sum
Checkpoint, °C	-7	-2	7	20	
BIN temperature limits, °C	-15 to -3	-2 to 4	5 to 15[a]	15[a] to 32	
month	monthly hourly rate in h / degree hours in Kh				
January	156/4,103	392/7,705	196/2,335	0/0	744/14,143
February	90/2,208	436/8,239	140/1,724	6/0	672/12,171
March	41/975	337/6,172	349/4,219	17/0	744/11,366
April	4/83	142/2,527	463/4,920	111/0	720/7,530
May	0	13/224	425/3,920	306/0	744/4,144
June	0	0	301/2,470	419/0	720/2,470
July	0	0	131/921	613/0	744/921
August	0	0	146/986	598/0	744/986
September	0	0	411/3,584	309/0	720/3,584
October	0	93/1,692	597/5,955	54/0	744/7,647
November	34/824	317/6,032	369/4,606	0/0	720/11,462
December	154/3,793	424/8,171	166/2,231	0/0	744/14,195
Year	479/11,986	2,154/40,762	3,694/37,871	2,433/0	8,760/90,619
[a] The temperature BIN 15 °C is split in half.					

By using heat pump test results, the maximum heat output, the power consumption and the coefficient of performance of the heat pump under the checkpoint temperatures in the second line of the above table are calculated through interpolation. If such test results are not available, default values given in Appendix C of DIN V 18599-5 can be used.

In the next step, the load factor of temperature class i in each month (FC) is calculated as the ratio of $Q_{h,outg,i}$ to the maximum heat output of the heat pump, and the partial load factor (f_{Pint}) is determined by referring to the tables also given in Appendix C. For electrically driven air-air heat pumps, the following table is used to determine the partial load factor (f_{Pint}).

Table 14 Correction factor for partial load operation (f_{Pint}) for electrically driven outside air-room air heat pumps with direct condensation

system	Load factor FC %									
	10	20	30	40	50	60	70	80	90	100
Compact devices (window or wall)	0.39	0.6	0.7	0.75	0.78	0.82	0.85	0.88	0.93	1.0
Split systems (also simultaneous multi)	0.4	0.65	0.75	0.78	0.81	0.85	0.9	0.92	0.95	1.0
Multi-split systems	0.54	0.85	0.94	0.98	1.02	1.02	1.0	1.0	0.99	0.98
VRF systems (variable refrigerant mass flow)	0.65	1.07	1.15	1.15	1.17	1.15	1.10	1.07	1.01	0.98

Finally, the coefficient of performance ($COP_{Pint,i}$) under the load factor (FC) and the temperature class i is calculated using the following equation, and the heat pump energy use ($Q_{h,f}$) is also calculated.

$$COP_{Pint,i} = f_{Pint} \times COP_{hp,\theta_{source},max} \qquad (10)$$

$$Q_{h,f} = \sum_{i=1}^{n_{class}} \frac{Q_{h,outg,i}}{COP_{Pint,i}} \qquad (11)$$

where

$COP_{hp,\theta source,max}$ is the maximum heat output of the heat pump under the source temperature (checkpoint temperature representing each temperature class)

n_{class} is 4, the number of temperature classes.

5.3 Italy: UNI/TS 11300

5.3.1 Structure of UNI/TS 11300

UNI/TS 11300 is the Italian technical specification for the calculation of primary energy use for heating, cooling, ventilation, domestic hot water and lighting for non-residential buildings. The use of UNI/TS 11300 is in compliance with the Italian Ministerial Decree 26/06/2015, "Application of calculation methods of energy performance and establishment of requirements and minimum requirements for buildings" (MD).
According to the MD, the notional reference building (also named target building) is characterized by reference values of the following parameters.

a) U-value of the envelope components
b) Total solar energy transmittance of windows in presence of shading device.
c) Efficiency of the heat utilization and of the generation subsystems for space heating, cooling and DHW
d) Features of lighting and ventilation systems

New and existing buildings subject to major renovation should meet the minimum requirements. The results of the energy calculation are recorded in a technical report formatted in accordance with the national energy regulation. The technical report is submitted to the local municipality. The results are reported in energy performance certificates, which are issued for buildings or building units, which are constructed , sold or rented out to new tenants.
UNI/TS 11300 consists of six parts listed in Table 15. Among the parts, Part 1-3 are especially relevant to HVAC energy calculation.

Table 15 List of Parts in UNI/TS 11300 (as of July 2019), Energy performance of buildings

Part 1: Evaluation of energy need for space heating and cooling
Part 2: Evaluation of primary energy need and of system efficiencies for space heating, domestic hot water production, ventilation and lighting for non-residential buildings
Part 3: Evaluation of primary energy and system efficiencies for space cooling
Part 4: Renewable energy and other generation systems for space heating and domestic hot water production
Part 5: Evaluation of energy performance for the classification of building
Part 6: Evaluation of energy need for lifts, escalators and moving walkways

There are six Italian climatic zones (A to F) according to Heating Degree Days.

5.3.2 Heating and Cooling Needs Calculation Zoning

Tables with typical occupancy patterns and associated values for various internal heat sources are provided. The tables include schedules of room usage, heat gains due to occupancy, lighting and appliances, air flows and time fractions of mechanical ventilation, heating and cooling operation. Both daily schedule(s) and monthly values are defined.
Eight building categories are defined: accommodation; office; health care; leisure, assembly and worship; shop and trade service; sport facility; educational; industrial building and craft workshop.
In the calculation, continuous heating and cooling is assumed for all room categories. The set-point room temperature and humidity are defined for each room category. The minimum ventilation rate is given taking into account the building type and the pattern of occupancy. For the mechanical ventilation, an additional air flow rate induced by wind effects through ventilation openings and cracks is also taken into consideration.

5.3.3 Energy Needs and Energy Use Calculation for Heating and Cooling

The methodology is based on the monthly method as specified in ISO 13790[7]. The model is refined to better fit the behavior of typical Italian buildings in local climates. National boundary conditions and input data

[7] ISO 13790 has been succeeded by ISO 52016-1:2017, which is introduced in 6.1.2.

are defined.

The building is partitioned into different thermal zones. For each building zone and for each month, the energy needs for heating and cooling are calculated by a balance of heat transfer (transmission + ventilation) and heat gains (solar + internal), in average monthly conditions.

For heating, a utilization factor for the internal and solar heat gains takes account of the fact that only part of such heat gains is utilized to decrease the energy need for heating, the rest leading to an undesired increase of the internal temperature above the set-point.

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} \times Q_{gn} = (Q_{H,tr} + Q_{H,ve}) - \eta_{H,gn} \times (Q_{int} + Q_{sol,w}) \tag{12}$$

where

$Q_{H,ht}$ is the total heat transfer for the heating mode,

$Q_{H,tr}$ is the total heat transfer by transmission for the heating mode,

$Q_{H,ve}$ is the total heat transfer by ventilation for the heating mode,

Q_{gn} gives the total heat gains,

Q_{int} is the sum of internal heat gains,

$Q_{sol,w}$ s is the sum of heat gains due to solar radiation on glazed elements, and

$\eta_{H,gn}$ is the dimensionless gain utilization factor.

For cooling, a utilization factor for the transmission and ventilation heat transfer takes account of the fact that only part of such heat transfer is utilized to decrease the cooling needs, the rest leading to a decrease of the internal temperature below the set-point occurring during periods or intervals (e.g. nights).

$$Q_{C,nd} = Q_{gn} - \eta_{C,ls} \times Q_{C,ht} = (Q_{int} + Q_{sol,w}) - \eta_{C,ls} \times (Q_{C,tr} + Q_{C,ve}) \tag{13}$$

where

$Q_{C,ht}$ is the total heat transfer for the cooling mode,

$Q_{C,tr}$ is the total heat transfer by transmission for the cooling mode,

$Q_{C,ve}$ is the total heat transfer by ventilation for the cooling mode, and

$\eta_{C,ls}$ is the dimensionless utilization factor for heat losses.

The results for different zones served by the same systems are combined and the energy use for heating and for cooling is calculated taking into account the dissipated heat of the heating and cooling systems. The auxiliary energy use (e.g. pumps, fans) of the HVAC systems is calculated separately and added.

The calculation method facilitates the energy analysis of the different sub-systems of the HVAC system, including emission, control, distribution, storage, generation (see Figure 2). For each sub-system the method determines the energy losses and the performance factors (efficiency).

The energy used by the HVAC system is calculated separately for thermal energy and auxiliary energy.

The energy balance of technical building systems is performed on a monthly basis, except for heat pumps that are analyzed through the bin method.

The results of thermal need calculation for each zone are summed up 1) for each group of heat emitters, 2) each group of distribution systems and 3) each group of heat generators. In those steps, calculations of energy use for fans, pumps and heat generators are done.

The HVAC system is assumed to be composed of heat emitters, distribution systems and heat generators. Fan coil units, split systems, nozzles, radiant panels are included in the definition of heat emitters. The distribution system includes air distribution and water distribution. The water distribution system supplies cold or hot water to the air-handling units, fan coils and radiant panels. The primary pumps, cooling towers, pumps for cooling water, pumps for heat storage and outdoor units for packaged air-conditioning systems are included in the definition of the heat generators.

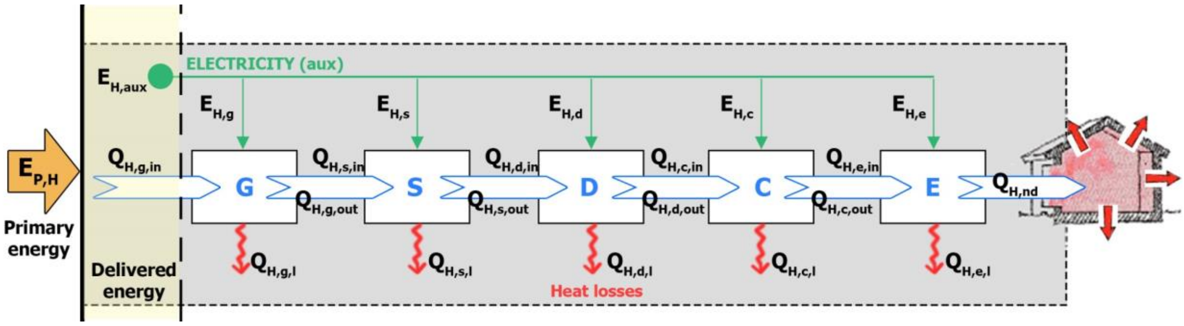


Figure 2 Subsections of HVAC system (Generation, Storage, Distribution, Control, Emitter)

Input parameters for heat pumps and boilers are as follows.

Heat pumps:

1) type and controller setting of the heat emission system

- flow temperature of the heating system dependent on the outdoor air temperature,
- temperature spread at design conditions

2) heat pump characteristics for heating capacity

3) COP according to product test standards and guaranteed temperature level that can be produced with the heat pump.

4) results for part load operation

5) system configuration

- installed back-up heater: operation mode, efficiency
- installed heating buffer storage: stand-by loss value, flow temperature requirements

6) power of auxiliary components (source pump, storage loading pump, primary pump, stand-by consumption)

Boilers:

1) generator output at full load,

2) generator efficiency at full load,

3) generator average water temperature at test conditions for full load

4) correction factor of full-load efficiency

5) generator output at intermediate load

6) generator efficiency at intermediate load

7) generator average water temperature at test conditions for intermediate load

8) correction factor of intermediate load efficiency

9) stand-by heat loss at test temperature difference $\Delta\theta_{i,test}$

10) difference between mean boiler temperature and test room temperature in test conditions

11) power consumption of auxiliary devices at full load

12) power consumption of auxiliary devices at intermediate load
13) stand-by power consumption of auxiliary devices
14) minimum operating boiler temperature.

Heat loss from ducts and pipes can be calculated either through analytical calculations or through a simplified methodology based on tabulated values of distribution efficiency.

The commissioning, especially that in the initial stage such as just after the building completion, is recognized to be very influential on the actual energy performance of the buildings and their HVAC systems. However, it has yet to be taken into consideration in the energy calculation.

The detailed calculation method for air-conditioning in summer is prescribed in UNI/TS 11300-3 "Evaluation of primary energy and system efficiencies for space cooling". In order to take into account the variation of electricity and gas consumption according to the climatic conditions, boundary conditions, the conditions of the machine including partial load factor, EN 14825:2018 (See 6.2) is referred to for refrigerating units with compressors, and EN 12309-3: 2014 is referred to for absorption refrigerating units. By referring to those standards, manufacturers can provide EER (Energy Efficiency Ratio) values for the refrigerating units with compressors, and GUE for the absorption refrigerating units. For lower load factor below 25%, the ratio of each EER to the EER at 25% is given as shown in Figure 3 in chapter 5.5 of UNI/TS 11300-3. The curve is used when calculating the monthly average energy efficiency of the refrigerating units.
The conditions when the EER values are to be measured are given also in chapter 5.5, as shown in Table 16.

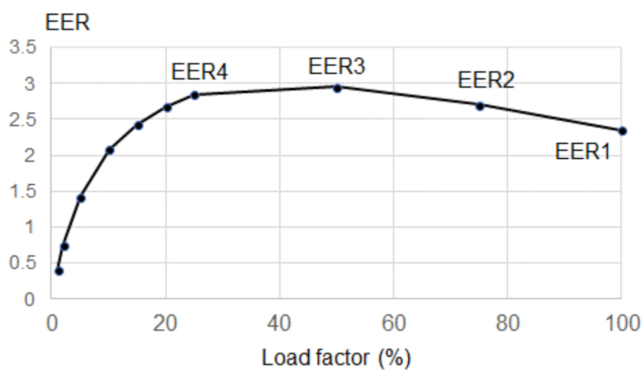


Figure 3 Example of trend of the EER values of a refrigerating unit with compressor according to load factor

Table 16 Reference conditions for determining the EER values in different partial load conditions of the refrigerating machines

Type		Air-to-air		Water-Air		Air-Water		Water-Water	
Test	Load factor F	Dry bulb outdoor air (°C)	Internal air dry bulb / wet bulb (°C)	condensation water in/out of the tower evaporative (°C)	Internal air dry bulb / wet bulb(°C)	dry bulb outdoor air (°C)	chilled water In Entry/exit of the fan coils (°C)	Condensation water In Tower inlet / outlet evaporative (°C)	chilled water In Entry / exit of fan coils (°C)
1	100 %	35	27/19	30/35	27/19	35	12/7 7/18	30/35	12/7
2	75%	30	27/19	26/*)	27/19	30	*)/7	26/*)	*)/7
3	50%	25	27/19	22/*)	27/19	25	*)/7	22/*)	*)/7
4	25%	20	27/19	18*)	27/19	20	*)/7	18*)	*)/7

*) Temperature determined by the flow rate of water at full load.

For taking into consideration discrepancy of temperature conditions between those prescribed in Table 16 and actual ones, monthly average energy efficiency of cold generators $\eta_{mm,k}$, discrepancies of temperature conditions between those prescribed in Table 16 and actual ones are adjusted by using $\eta_1(F_k)$ in the following equations. By the equation, other actual conditions of the refrigerating unit are also taken into consideration. The other conditions include 1) fan speed of indoor unit, 2) pipe length between indoor and outdoor units, 3) air flow rate through duct connected to indoor unit, 4) water flow rate, 5) temperature difference before and after terminals, etc.

$$\eta_{mm,k} = \mathrm{EER}(F_k) \times \eta_1(F_k) \times \eta_2 \times \eta_3 \times \eta_4 \times \eta_5 \times \eta_6 \times \eta_7 \quad (14)$$

where

$\eta_{mm,k}$ is monthly average energy efficiency of cold generators,

EER(F_k) is the energy efficiency ratio obtained in correspondence with the load factor F_k, which can be obtained by interpolating from the curves of the EER,

$\eta_1(F_k)$ is the corrective coefficient obtained at load factor F_k, and can be obtained by double interpolation from the tables in Appendix C of UNI/TS 11300-3,

η_2, η_3, η_4, η_5, η_6, η_7 are the correction coefficients that can be obtained from the tables in Appendix D of UNI/TS 11300-3, and

k represents month.

F_k is the average monthly load factor, calculated as the ratio between the amount of thermal energy required for cooling and ventilation ($Q_{Cr} + Q_v$) in the month k-th and the maximum value of the energy delivered by the refrigerating machine in the same month (ie: h x Φ_n, where h is the number of hours per month and Φ_n the rated power of the refrigerating machine);

EER (F_k) is the energy efficiency ratio obtained in correspondence with the load factor F_k, which can be obtained by interpolating from the curves of the EER constructed according to the indications in point 5.5.1;

η_1 (F_k) is the corrective coefficient obtained at load factor F_k, and can be obtained by double interpolation from the tables in Appendix C;

η_2, η_3, η_4, η_5, η_6, η_7 are the correction coefficients that can be obtained from the tables shown in Appendix D.

5.4 Japan: BECS

5.4.1 Structure of BECS

In Japan, the implementation of the method of primary energy calculation for non-residential buildings for compliance checking in accordance with the Building Energy Conservation Standard (hereinafter abbreviated as "BECS") was initiated in April 2013. This replaced the former method which separately evaluated the efficiencies of the building envelope, HVAC, ventilation for non-air-conditioned space, DHW system, lighting and elevator. Figure 4 shows the overall structure of the calculation method.

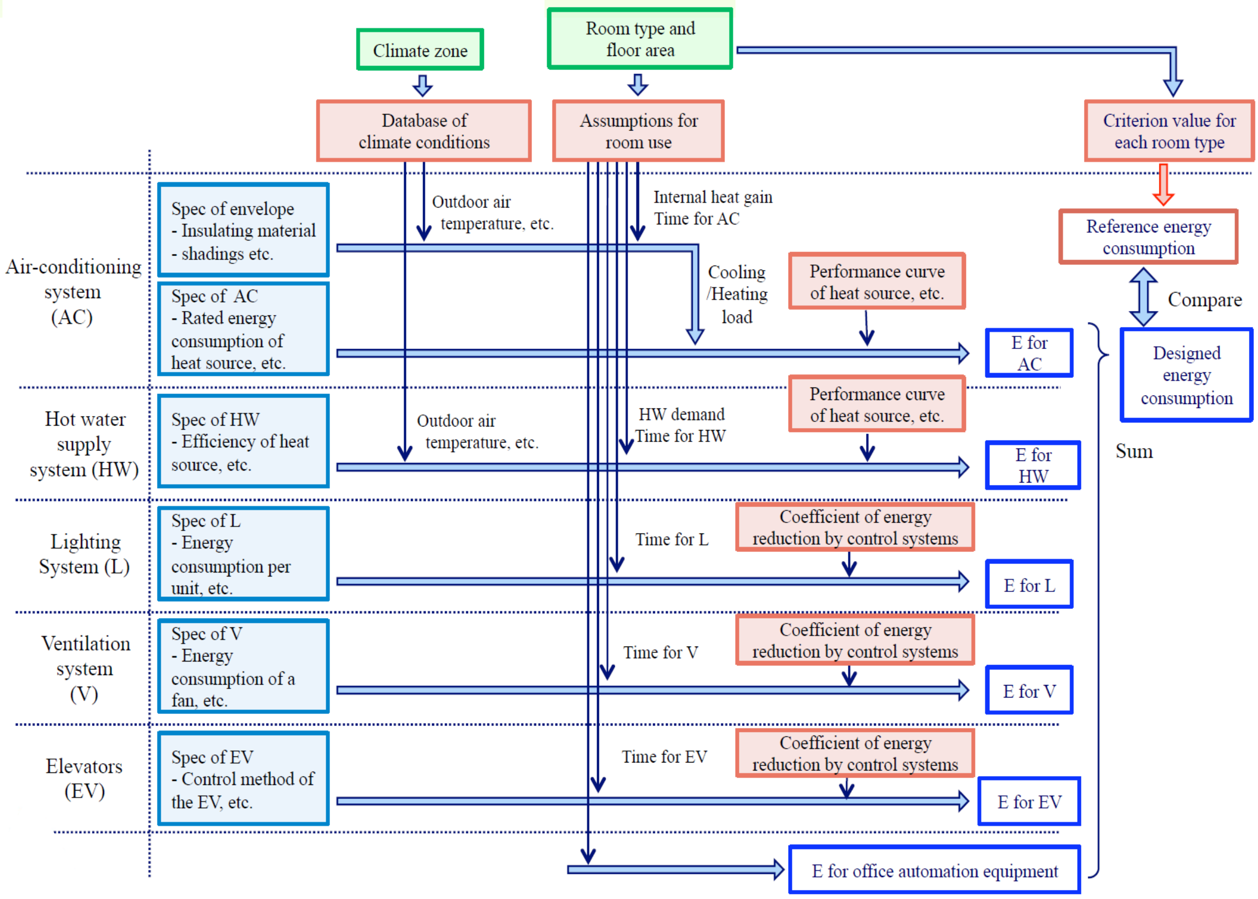


Figure 4 Overall Structure of BECS

BECS was developed and is jointly maintained by the Housing Bureau of MLIT, NILIM, BRI and JSBC. It is a web-based program, which enables users to calculate primary energy use for HVAC, DHW, lighting system, ventilation system for non-air-conditioned space and elevator. As a web-based program, it has become easier to strictly control the version, which can be used when users submit their report to municipalities for the permission to build. As of June 2018, for new construction of non-residential buildings with a floor area not less than 2,000 m^2, it is mandatory to submit a report and obtain proof of compliance issued by municipalities or by qualified private organizations for the compliance decision. It was decided to legally extend the target to buildings with floor area not less than 300 m^3 after April 2021.

For the BECS, 201 types of room usage (conditions of use) are prescribed for the following parameters.

a) Daily schedule for internal heat gains due to lighting, occupants and appliances
b) Operating hours of HVAC, lighting and ventilation for non-air-conditioned room
c) Set-point temperature and relative humidity
d) Ventilation (outdoor air supply) requirement
e) Maintained illuminance
f) Daily domestic hot water use per occupant, per bed or per floor area
g) Allocation of daily schedules (up to three types) to 365 days

An example of daily schedules and room use conditions is shown in Figure 5 for the office room of office buildings. There are eight climatic zones, which are divided according to Heating Degree Days of the locations of the administrative hall of each city, ward, town and village.

Whole conditions of room usage for BECS are included in Annex B (informative) of ISO 18523-1:2016, “Energy Performance of buildings – Schedule and condition of building, zone and space usage for energy calculation – Part 1: Non-residential buildings”.

5.4.2 Definition of Rooms and Air-Conditioning Zones in Evaluated Buildings

In preparing input data, the whole interior space of the building is divided into rooms. Each of the spaces partitioned by inner walls is divided into separate rooms. If a partitioned space contains various types of room (e.g. office and meeting room), it is divided into rooms for each of the types of room usage.
The air-conditioning zone is defined as a room or a group of rooms, which is serviced by a common group of air handling unit and the like. The air handling unit and the like is defined as heat or cold emitters including air handling unit, fan coil unit, indoor unit of ductless multi-split system with VRF, radiator, radiant heating and cooling panel and ventilation unit with or without heat recovery function. If a space is air-conditioned by different kinds of air handling unit and the like, and if they are controlled independently, the space shall be divided into separate rooms and air-conditioning zones. If a space is air conditioned by multiple indoor units belonging to their common ductless multi-split system with VRF, the space shall be defined as a single air-conditioning zone. The energy calculation for space heating and cooling is undertaken for each of the air-conditioning zones.

5.4.3 Energy Needs and Energy Use Calculation for Heating and Cooling

The calculation of heating and cooling needs is undertaken for each air-conditioning zone.
The steady state heating and cooling needs due to heat transmission and solar heat gain are calculated daily for each of the air-conditioning zones by using daily average temperature and daily total radiation. These are converted into the daily total heating and cooling needs calculated with the dynamic calculation, by using linear regression lines pre-installed in the calculation tool (Figure 6). In preparing regression lines, a response factor method and the software "New HASP", which is most commonly used in Japan for practices, is applied. In the next step, daily total internal heat gain is added to the daily total heating and cooling needs due to heat transmission and solar heat gain. Following this, the heating and cooling needs due to outdoor

air intake are added to those due to heat transmission, solar heat gain and internal heat gain to obtain the total heating and cooling needs for the group of air handling unit and the like servicing the air-conditioning zone.

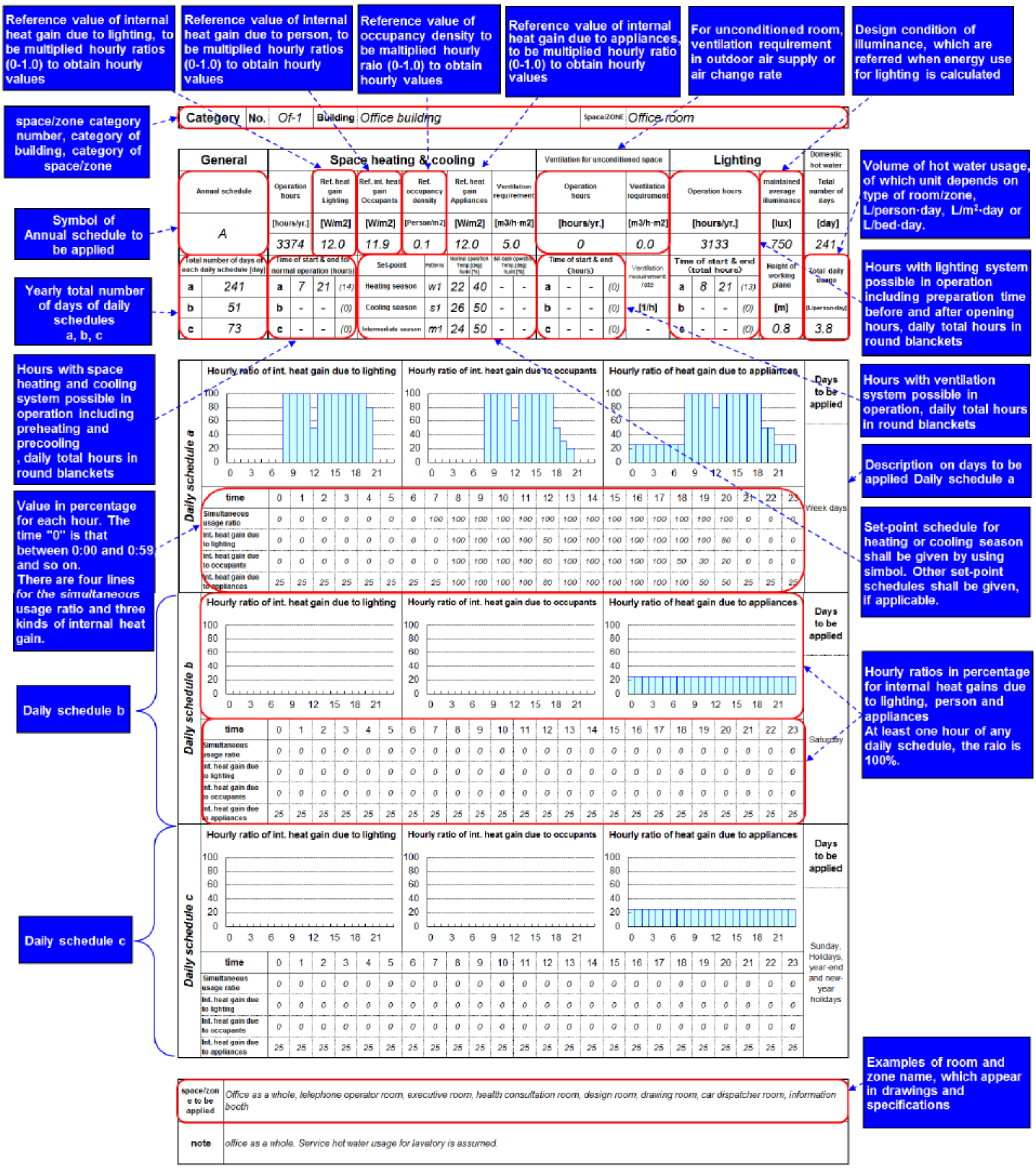


Figure 5 An example of daily schedules and room use conditions (office room of office building)

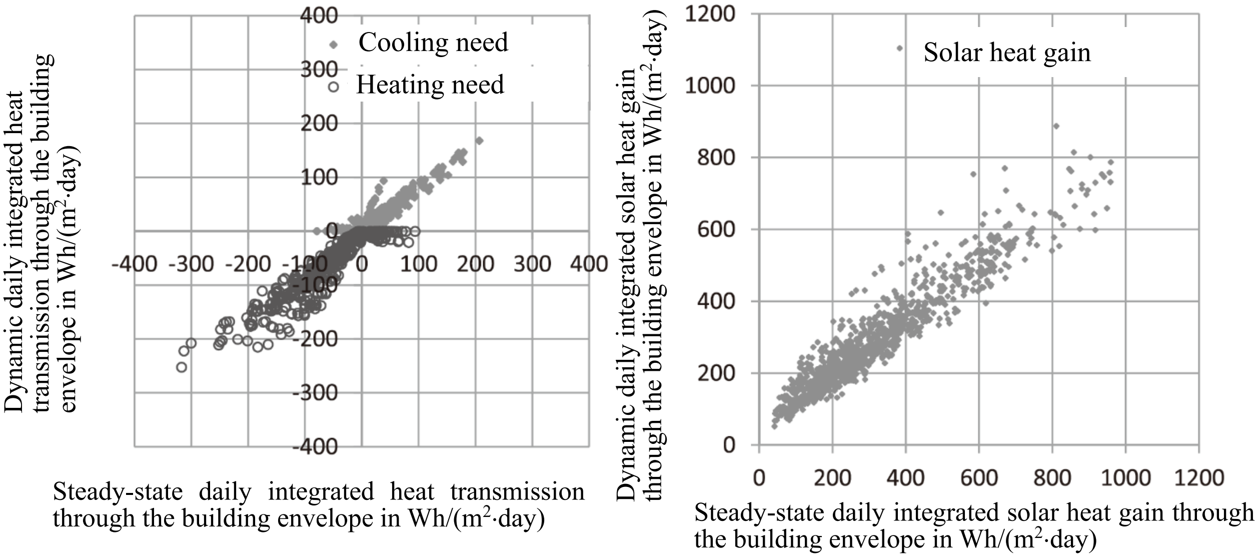


Figure 6 Correlation between steady-state and dynamic calculations for daily integrated heat transmission and solar heat gain through the building envelop (regression lines are obtained separately for room use, season and the condition of the previous day

The daily total heating or cooling needs for the group of air handling unit and the like is evenly divided into each of operating hours for air-conditioning (heating and cooling). The partial load ratio, $L_{AC,auh,c,i,d}$ (in case of cooling), is defined as the ratio of the hourly heating or cooling need to the rated heating or cooling capacity of the group of air handling unit and the like and is calculated and tabulated into eleven ranges from 0<= $L_{AC,auh,c,i,d}$ <0.1 to 1.0<= $L_{AC,auh,c,i,d}$. Hourly electricity consumption for the group of air handling unit and the like when with air flow volume control is calculated by using $L_{AC,auh,c,i,d}$, the rated electricity consumption, the minimum air flow volume ratio, the rated air flow volume and the relationship between $L_{AC,auh,c,i,d}$ and electric consumption.

The heat emission from the air handling unit and the like by their fans is added to heating or cooling need, which is dealt with by secondary pumps connected to the group of air handling unit and the like. Taking into account inlet and outlet water temperature of the piping network, hourly water flow volume is calculated and its ratio, $L_{AC,pump,i,d}$, to the rated water flow volume of the secondary pumps is tabulated into eleven ranges from 0<= $L_{AC,pump,i,d}$ <0.1 to 1.0<= $L_{AC,pump,i,d}$. Hourly electricity consumption for the secondary pumps when with water flow volume control is calculated using $L_{AC,pump,i,d}$, the rated electricity consumption, the minimum water flow volume ratio, the rated water flow volume and the relationship between $L_{AC,pump,i,d}$ and electric consumption.

The heat emission from the pumps is added to heating or cooling need, which is dealt with by heat generators connected with the secondary pumps. The ratio, $L_{AC,ref,i,d}$, of the hourly total heating or cooling need, which is dealt with by the heat generators, to the rated heating or cooling capacity of the heat generators is tabulated into eleven ranges from 0<= $L_{AC,ref,i,d}$ <0.1 to 1.0<= $L_{AC,ref,i,d}$ and into six ranges of outdoor temperature of each hour, as shown in Table 17.

Table 17 An example of tabulated cooling need for a group of generators into the table with ranges of the partial load ratio, $L_{AC,ref,i,d}$ and outdoor temperature (frequency of hours in italics)

Partial load ratio		0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1.0	1.0-
Outdoor temperature ° C	-10	*28*	*14*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	10-15	*0*	*322*	*98*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	15-20	*0*	*14*	*350*	*98*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	20-25	*0*	*0*	*14*	*504*	*168*	*28*	*0*	*0*	*0*	*0*	*0*
	25-30	*0*	*0*	*0*	*0*	*210*	*280*	*70*	*0*	*0*	*0*	*0*
	30-	*0*	*0*	*0*	*0*	*0*	*7-*	*14*	*0*	*0*	*0*	*0*

The maximum heat output of each generator is estimated by referring to its rated capacity and the correction factor as functions of outdoor air conditions or cooling water temperature, which are given for each type of heat generator in a relevant document for the calculation method. If the number of operated generators among a group of generators is controlled, the number is determined as the minimum number of generators, of which total maximum heat output is above the heating or cooling need. The energy use of each heat generator is estimated by referring to its rated input energy use, partial load ratio, conditions of outdoor air or cooling water, outlet hot/cold water temperature. The total energy use of a group of heat generators at each hour is calculated by summing up energy uses of all heat generators.

5.5 Switzerland: SIA

5.5.1 Structure of relevant SIA standards and documents

The list of relevant Swiss standards and documents is given in Table 18. The SIA is the Swiss Society of Engineers and Architects, which is Switzerland's professional association for construction, technology and environment experts.

Table 18 List of SIA standards and documents relevant to HVAC energy calculation

Standards
SIA 382/2 Air-conditioned buildings – power and energy requirement
SIA 382/1 Ventilation and air conditioning - General principles and requirements
Leaflets
SIA 2044 Air-conditioned buildings - Standard calculation method for the power and energy requirements
SIA 2024 Use of space data for energy and building technology
SIA 2028 Climate data for building physics, Energy and building technology

The most important documents for the Swiss national calculation method for HVAC are SIA 382/2, SIA 2044 and SIA 2024. SIA 382/2 prescribes an overall structure to calculate energy use for space heating, cooling and ventilation. The calculation is implemented in the time step of 1 hour or less. The calculation method is supposed to be used for three different tasks, as follows:

1) Planning and optimization in design stage for a construction or a retrofit project
2) Proof of complying with the performance requirement prescribed in SIA 382/2
3) Comparison of the calculated energy use with the actual energy use in existing buildings

For proof of compliance, standardized conditions of building and room usage, which are prescribed by SIA 2024, and the same climatic data, by which the requirements have been calculated, must be used. For the planning/optimization and comparison with the actual energy use, the most suitable values for use and climate must be used. For the planning/optimization, which is undertaken at an early stage and where many parameter may be unknown, default values given in Annex A of SIA 2044 can be used as input parameters for energy calculations, until more accurate values are obtained at later stages.

The standard calculation method is prescribed in detail in SIA 2044, and SIA-TEC tool, which is the calculation program developed based on SIA 382/2 and SIA 2044 is publicly available. SIA 382/2 also prescribes the requirements for other calculation methods, which do not comply with the SIA standards. If any HVAC systems are not covered by the SIA standards, calculation methods satisfying the following requirements can be used for the associated energy calculations:

1) The requirements prescribed in Annex B of SIA 382/2 are met;
2) The calculation result for the HAVC system, of which energy use can be calculated by the standard calculation method, is similar to the result of the calculation method;
3) Validation is undertaken according to five IEA SHC Task 22 reports,

The other standards and documents relevant to building energy calculations are listed in Table 19.

Table 19 List of other SIA standards and documents relevant to broader energy calculation for buildings

Standards
SIA 380 Basics for energy calculations in buildings
SIA 380/1 Heating energy need
SIA 380/4 Electrical energy in building construction[8]
SIA 384/201 Heating systems in buildings - Method for calculating the standard heating load (SN EN 12831: 2003[9] with national annex)
SIA 384/3 Heating systems in buildings - plant technology and degree of utilization (in preparation)
SIA 385/2 Hot water supply for drinking water in buildings - Calculation methods for planning
Leaflets
SIA 2031 Energy pass for buildings

Note: SIA 380 contains the definition of building envelope and reference areas as well as the total energy balance method.

The conditions required for other calculation methods are prescribed in detail in Annex B of SIA 382/2. In addition to the requirements, validation according to the IEA SHC Task 22 publications (2001 and 2004) is required for relevant technical systems.

[8] SIA 380/4 was published in 2006, and was replaced by SIA 387/4 “Electricity in buildings – lighting: calculation and requirements” and SIA 2056 “Electricity in buildings – energy and power needs”.
[9] This was superseded by EN 12831-1:2017.

5.5.2 Zones for Heating and Cooling Needs Calculation

Reduction of lighting electricity use through daylighting is taken into consideration as described in chapter 2.2.4 of SIA 2044. For the reduction of heat gain due to lighting to be properly accounted for, zoning for thermal conditioning and lighting needs to be consistent, however clear zoning rules are yet to be found in SIA documents.

5.5.3 Energy Needs and Energy Use Calculation for Heating and Cooling

In the SIA 2044 calculation method, maximum heating and cooling needs for each room or zone is calculated with the assumption that there is no internal heat gain for heating and that the internal heat gain for cooling is higher than the SIA 2024 assumed value. Hourly heating, cooling and humidification needs can also be calculated by the standard method.

The detail of the SIA 382/2 calculation method is prescribed in SIA 2044, which was especially specified for computer program developers. The simplified hourly calculation model used is based on an equivalent resistance-capacitance model (node model). The model distinguishes between the room air temperature, mass temperature and "central temperature", which is a mixture of room air temperature, mass temperature and the surface temperature of windows and other external lightweight components. In the area of rooms which is closer to the façade and where window height is more than twice ceiling height (e.g. within 6m from the façade if the ceiling height is 3m), internal heat gains due to lighting can be reduced by taking into account lighting control (daylight control, constant light control, manual daylight control and presence control)

The air flow volume of air handling units is determined by taking into account 1) the quotient of the actual air flow volume at the time to the design value for demand control ventilation, 2) air leakage through ducts and air handling units, and, 3) increase of air flow volume for the HAVC system using recirculated air. Although the third factor of increasing air flow volume is considered, this Swiss standard calculation method recognizes that the use of air as a heat transfer medium is inefficient and mechanically distributed air over the amount for the indoor air quality should be discouraged according to 4.2.4.2, SIA 382/2. This guidance specifically relates to regions with a cooler summer, for which air-conditioning for only outdoor air supply is enough to maintain the whole overall indoor air temperature and humidity. Heat losses from ducts are calculated by using the temperature difference between inside and outside of ducts.

The fan-assisted air volume flows into and out of the air handling unit, $q_{V,AHU}$, are calculated using the following equation.

$$q_{V,AHU} = \frac{q_{V,req} \cdot C_{ctr} \cdot C_{i,lea} \cdot C_{RCA}}{\varepsilon_V} \tag{15}$$

where

$q_{V,req}$ is the required airflow rate that is supplied to each room or is removed from it,

C_{ctr}, $C_{i,lea}$, C_{RCA} are coefficients for local airflow control, for additional airflow requirement due to air leakage through ducts and air handling units, and for recirculated air, respectively, and

ε_V is the ventilation efficiency, which is the ratio between concentration of pollutant in the exhausted air and the mean concentration in the room.

The fan power consumption in partial load conditions, depending on the type of construction, is calculated by using cubic polynomials of the ratio between airflow rate under partial load conditions and the maximum airflow rate, for speed control, variable blade angle for axial fans and slip control. The relationship between the ratio of the airflow rates and partial load correction factor of fan power is shown in the following figure.

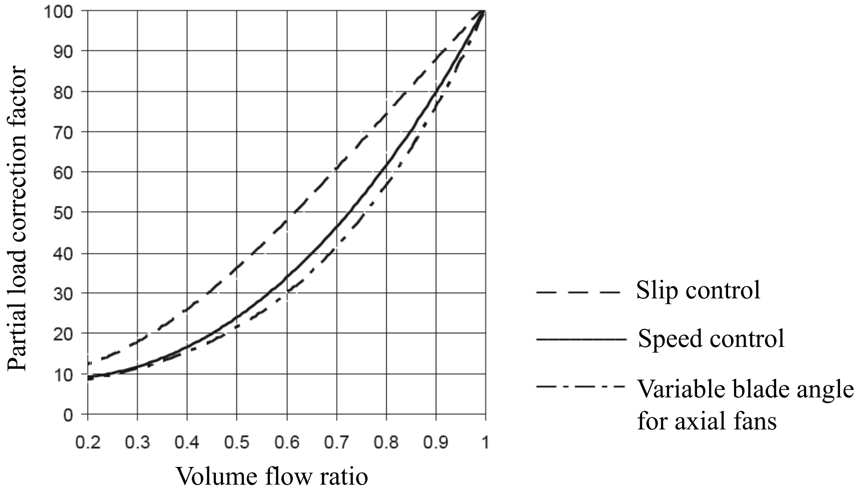


Figure 7 Curves for partial load correction factors for different fan controls[10]

The energy use for the air-conditioning system is calculated for components listed in Table 20.

[10] In SIA 2044:2019, which is the revision of SIA 2044:2011, this part for calculating fan energy use was revised and the method prescribed in EN 16798-5-1 (See Table 27 of this report) is referred. In the method, two fan control types for reducing fan energy use (constant fan pressure difference and minimum pressure difference) are dealt with.

Table 20 Components of air-conditioning system, of which energy use are calculated in SIA 2044

Components of air-conditioning system	Overview of the standard energy calculation method
1. Icing protection by preheating outdoor air	Pressure loss increase due to preheating through underground duct route, usage of bypass route to avoid icing in the heat recovery unit, usage of preheater and mixing outdoor air with recirculated air are considered.
2. Fan for exhausting air	Fan power at full load is multiplied by the factor for partial load condition according to type of fan control. When necessary, heat input by the fan is considered and the exhaust temperature is adjusted.
3. Heat recovery unit with heat exchanger	Change of heat exchange ratio of the heat recovery unit due to change of face air velocity, temperatures/humidity ratios and air flow volume ratio is calculated by using equations.
4. Preheater	Power of preheater is calculated with temperature difference between supply air temperature after the heat recovery unit and setpoint temperature.
5. Cooler and dehumidification	Power for cooling and dehumidification is calculated taking into account bypass factor.
6. Humidifier	Power for humidification is calculated.
7. Reheater	Power of reheater is calculated in the same way as preheater.
8. Fan for supplying air	Fan power at full load is multiplied by the factor for partial load condition according to type of fan control. For supply fan, heat input by the fan is considered and the supply temperature is adjusted according to the position of the motor.

Motor power for rotating heat exchanger and pump power for humidification are calculated as auxiliary energy use. Heat losses that occur at the stage of heat emission for heating and cooling into rooms (due to locally low temperature and less accurate temperature controls) are not necessarily calculated, and values are given as examples. Auxiliary energy use by pumps, fans and control systems for heating and cooling emitters is taken into account during the heating and cooling system operation time.

Heat losses from pipes at the heat and cold distribution stage are calculated taking into account their length, heat transfer coefficient and surrounding temperatures. Auxiliary energy use for pumps is calculated taking into account hydraulic power and efficiency of pumps. If the pump speed can be controlled, auxiliary energy for pumps is reduced by taking into account the heat output ratio of the distribution system at the time to their maximum output.

Energy efficiency of chillers ($\eta_{\mathrm{COP,C}}$) is given as a function of partial load ratio (ratio of current capacity to the nominal capacity of chillers, f_{PLR}) and temperatures of cold water and refrigerant at evaporator and condenser.

$$\eta_{COP,C} = \frac{273 + \theta_{e,out} - \frac{\Delta\theta_{COR}}{2}}{\theta_{C,in} - \theta_{e,out} + \Delta\theta_{COR}} \cdot \left(a \cdot f_{PLR}{}^{3} + b \cdot f_{PLR}{}^{2} + c \cdot f_{PLR} + d\right) \tag{16}$$

where

$\Delta\theta_{COR} = (\theta_C - \theta_e) - (\theta_{C,in} - \theta_{e,out})$

$\theta_{C,in}$ $\theta_{e,out}$ θ_C θ_e : temperature at condenser inlet of cooling water, at evaporator outlet of cold water, at condenser inlet of refrigerant, and at evaporator inlet of refrigerant, respectively

a, b, c, d : coefficients to be determined by test results for four operating points (100%, 75%, 50%, 25%)

f_{PLR} : partial load ratio (0 to 1.0)

The coefficients in the function are determined based on COPs at four partial load conditions (25%, 50%, 75% and 100%) according to the ARI 550/590-1998[11] test standard or Eurovent 6-C003-2006 (ESEER). Electrical power requirement for cooling towers is calculated with nominal capacity, specific electrical power supply of the cooling tower and part load air volume ratio.

Energy efficiency of boilers is calculated according to Section 5.3 “Case specific boiler efficiency method” of EN 15316-4-1 “Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-1: Space heating generation systems, combustion systems (boilers)”. This calculation method is based on three measurements for boiler efficiency at rated load, medium load (such as 30%) and zero load. The losses occurring under the current operating conditions are determined. The three points of these losses are linearly interpolated. The principle of the method is shown in the following figure. Similarly, the auxiliary energy requirement is determined through the interpolation of three test values.

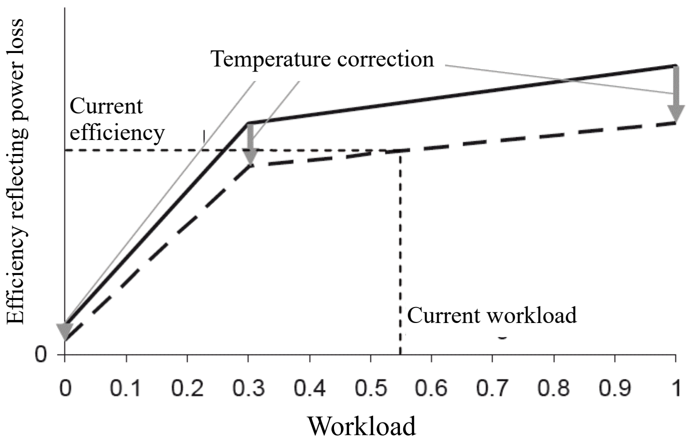


Figure 8 Principle of the calculation method of energy use for boilers

The two boiler efficiencies $\eta_{gen,P,N}$ at rated load and $\eta_{gen,P,int}$ at medium load are corrected taking into consideration the current boiler temperature according to the following equation.

$$\eta_{gen,Px,cor,j} = \eta_{gen,Px} + f_{cor} \cdot \left(\theta_{gen,test} - \theta_{gen,i}\right) \quad (17)$$

where

f_{cor} is correction factor for the respective utilization,

$\theta_{gen,test}$, $\theta_{gen,i}$ are mean boiler water temperature under test conditions and current mean boiler water temperature, respectively.

Electrical auxiliary energy use is calculated according to EN 15456 “Heating boilers - Electrical power consumption for heat generators - System boundaries – Measurements”.

[11] The latest version is AHRI 550/590-2018 “Performance Rating of Water-chilling and Heat Pump Water-heating Packages Using the Vapor Compression Cycle”

Energy efficiency of heat pumps is calculated by the method, which essentially corresponds to the detailed case-specific method according to EN 15316-4-2 “Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-2: Space heating generation systems, heat pump systems”. The required test data are the COP values and capacities according to the test conditions prescribed in EN 14511.
The method for calculating the annual employment rate of heat pumps depends on those in the Swiss program “WPesti”. This method, in turn, is essentially equivalent to the detailed case-specific method for calculating the annual work figure based on the data on the degree of utilization of the components according to clauses 5.3.5 and 5.3.6 of EN 15316-4-2, which apply to different applicable “bin” sizes. In contrast to the abovementioned methods, the performance figures are calculated every hour. The required input data are those under test conditions (test results of the WP Test Center), determined standard COP values and performances (according to EN 14511).

5.6 United Kingdom: SBEM

5.6.1 Structure of SBEM

SBEM is a computer program that provides an analysis of a building’s energy use. It was developed for the UK National Calculation Method (NCM), which is defined by the Department of Communities and Local Government (DCLG) in consultation with the Devolved Administrations (DAs-England, Wales, Scotland and Northern Ireland). The procedure for demonstrating compliance with the Building Regulations for buildings other than dwellings involves calculating the annual energy use for a proposed building and comparing it with the energy use of a “notional” building. The NCM allows the calculation either by an approved simulation software or by a simplified tool based on CEN standards. The simplified tool, SBEM – Simplified Building Energy Method, was developed for DCLG by BRE.
The Building Regulations compliance calculation generally compares the total energy use of the building and its systems (in $kWh/m^2/year$), expressed as carbon dioxide emissions of the building being evaluated (its “Building Emission Rate” or BER) with a target value (“Target Emission Rate” or TER) derived from similar calculations for a “notional building” (where both emission values are in $kgCO_2.m^2/year$). As of 2014, the Wales regulations uses the TEPC (primary energy consumption of the Notional Building) and CER (carbon emissions rate of the proposed building) benchmarks as variations of the TER for new and existing non-domestic buildings, respectively.
The notional building has the following characteristics (more detailed specifications are described such as in the Building Regulations Approved Document Part L for England):

- The same geometry, orientation, and usage as the evaluated building.
- The amount of glazing in the notional building is not the same as that in the evaluated building. The area of glazing is a certain percentage of external walls and roofs and is dependent on the use of the building.
- It is exposed to the same climatic conditions as the evaluated building.
- Standard operating pattern (standard use of rooms to allow consistent comparison between

buildings in the same sector).

- Standardized assumptions for building fabric, glazing type, and HVAC plant efficiencies.

The structure and flow of the calculation in SBEM is as in Figure 9.

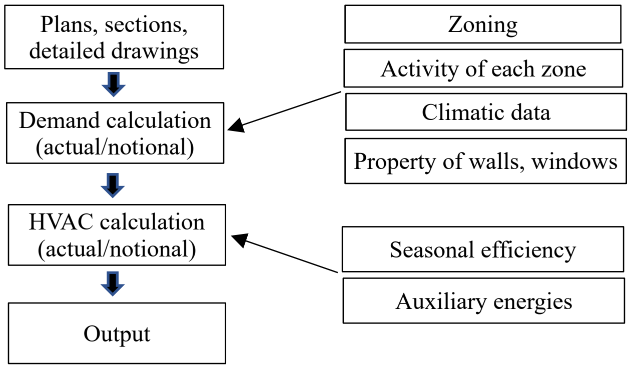


Figure 9 Structure and flow of the calculation in SBEM

The use of rooms and zones is defined and given as the Activity database. The database contains a comprehensive list of 22 building types, and 77 space types (activity types). The CIBSE (Charted Institution of Building Services Engineers) climatic data for fourteen sites is available for Test Reference Year as standard weather data sets for the calculation. There is no climatic zone, and climatic data for the location closest in distance to the actual site of the project, is used for the calculation. The weather data includes dry and wet bulb temperature, global and diffuse solar radiation (no long-wave radiation), and wind speed and direction in hourly basis, which are used to prepare monthly values for the SBEM calculation.

Examples of specifications of the notional building are shown in Table 21, Table 22 and Table 23. Table 23 is only for heating system, and the cooling SSEER, which is the ratio of the sum of the sensible cooling energy need of all spaces served by a system to the energy content of the electricity or fuel supplied to the chillers or other cold generators of the system, is 3.6. The SSEER value includes 20 % additional energy use due to distribution losses and fan energy use associated with heat rejection such as by cooling tower.

Table 21 Example specifications of the notional building (thermal transmittance expressed as U-value, and thermal capacity)

Exposed element	U-value (W/m^{2}k)	Thermal capacity (kJ/m^{2}K)
Roofs (irrespective of pitch)	0.18	21.8 (1.40 if metal-clad)
Walls	0.26	88.3 (1.40 if metal-clad)
Exposed floors and ground floors	0.22	77.7
Windows	1.60	-
Roof windows and roof-lights	1,80	-

Table 22 Example specifications of the notional building (glazing area, "g-value" representing the fraction of incident solar radiation transmitted by a window, etc.)

Activity glazing class	Glazing area (glass + frame)	g-value (EN 410)	Frame factor	Visible light transmittance
Side-lit	Exposed facades will have windows with area that is the lesser of either: 1.5m high ×full façade width OR 40% of exposed façade area	40%	10%	71%
Top-lit	12% of exposed roof area will be made up of roof-lights	55%	15%	60%
Unlit	No windows or roof-lights	n/a		

Table 23 Example specifications of the notional building (heating system SCoP is shown in percentage)

Heating fuel used in the Actual building	SCoP for Space heating	SCoP forHot water	Heating fuel emission factor in the Notional building ($kgCO_2/kWh$)
Biofuels (i.e., whose emission factor < emission factor of natural gas)	63.0%	66.5%	The factor for the particular biofuel
Natural gas	81.9%	86.45%	0.216
LPG			0.241
Dual fuel (Mineral + Wood)			0.226
Fuel oil			0.319
Electric heat pump	243.0%	256.5%	0.519
Non-electric heat pump	126.0%	133.0%	The factor for the particular fuel
Electricity (direct)	81.9%	86.45%	0.319
Other fuels (i.e., whose emission factor > emission factor of fuel oil)			

Note: SCoP is the ratio of the sum of the heating energy need of all spaces served by a system to the energy content of the fuels or electricity supplied to heat generators of the system. The energy content includes efficiency of heat generators, heat losses in pipework and duct leakage.

In addition to Building Regulations compliance, SBEM is used for UK Energy Performance Certificate purposes. To determine the energy rating for Energy Performance Certificates (EPCs) for England, Wales and Northern Ireland, the "reference building" is defined. The CO_2 emissions from an actual evaluated building is compared with a Standard Emission Rate (SER), which is determined by applying a fixed improvement factor to the emissions from a reference building. The reference building is defined irrespective of (a) whether the actual building is naturally ventilated or equipped with full HVAC system, and (b) the fuel choice in the actual building. The insulation levels and HVAC efficiencies in the reference building are identical to the notional building except that certain parameters in the reference building are fixed irrespective of features in the actual building. The fixed parameters in the reference building are as follows:

a. The heating and hot water service is always met by a gas-fired system.
b. The spaces in the reference building have a fixed servicing strategy regardless of the strategy adopted in the actual building:

- Each space is heated to the heating setpoint defined in the activity database, except if the corresponding space in the actual building is totally unconditioned.
- Each space is cooled to a fixed cooling setpoint, except if the corresponding space in the actual building is totally unconditioned.
- Each space which is unconditioned, i.e., unheated and uncooled, in the actual building will also be unconditioned in the reference building.
- Each space is naturally ventilated, irrespective of whether the corresponding space in the actual building has natural or mechanical ventilation.

The CO_2 emissions from the use of the fixed building services in the reference building are calculated (the Reference Emission Rate or RER), and then adjusted by an improvement factor of 23.5%. This adjusted CO_2 emission rate is termed the Standard Emission Rate (SER). The Asset Rating (AR) in England, Wales and Northern Ireland is the ratio of the CO_2 emission from the actual building to the Standard Emission Rate multiplied by 50 and rounded to the nearest whole number.

The purpose of SBEM and its basic user interface iSBEM is to produce consistent and reliable evaluations of energy use in non-residential buildings for Building Regulation Compliance and also for Building Energy Performance Certification. In introductions of relevant documents, the following caution is described:

"SBEM is a compliance procedure and not a design tool. If the performance of a particular feature is critical to the design, even if it can be represented in SBEM, it is prudent to use the most appropriate modelling tool for design purposes. In any case, SBEM should not be used for system sizing." (p.11 in User Guide iSBEM (1) Basics – UK, 20 November 2015)

"The need is to ensure that comparisons with the notional and other buildings are made on a standardized, consistent basis. For this reason, the energy and CO_2 emission calculations should not be regarded as predictions for the building in actual use." (p.20 in A Technical Manual for SBEM, UK volume, 20 November 2015)

5.6.2 Heating and Cooling Demand (Need) Calculation Zones

Zoning rules are described in National Calculation Methodology modelling guide (pp. 54-55 in 2013 Edition). There are two types of zone, "thermal zone" and "lighting zone". The same zoning arrangement must be applied in the notional building and the reference building. In the actual building, zoning is defined by the extent of the control systems that modulate the output of HVAC and lighting systems.
Zoning of spaces in an actual evaluated building is started by dividing spaces with physical boundaries, such as partition walls and floors.

Note: In documents for SBEM, "demand" is used instead of "need". Therefore, for the descriptions on the SBEM in this report, "demand" is used, while "need" is used in other parts of this report because "need" is mainly used in ISO and CEN standards.

A thermal zone is an area that:

a. has the same heating and cooling setpoints;
b. the same ventilation provisions;
c. the same plan operating times;
d. the same set-back conditions;
e. is served by the same type(s) of terminal device;
f. the same primary plant; and
g. the output of each type of terminal device is controlled in a similar manner.

A lighting zone is an area that:

a. has the same lighting requirement (level and duration);
b. is served by the same type(s) of lamp/luminaire combination;
c. the output of the lighting system is controlled in a similar manner and
d. has similar access to daylight, i.e., the zone is bounded with fenestration having similar glazing ratio, lighting transmittance, and orientation. This means that where benefit is being taken of daylight-linked controls (manual or automatic), a given lighting zone must not extend beyond 6m from the perimeter.

A thermal zone can contain multiple lighting zones, but a lighting zone cannot extend across the boundary of a thermal zone. Adjoining thermal zones (horizontally or vertically) may be combined into a single larger zone, if they have the same combination of activities and lighting zones, and the same characteristics of façade.

5.6.3 Heating and Cooling Energy Demand and Energy Consumption Calculation

For the calculation of heating and cooling demand, a monthly calculation in accordance with ISO 52016-1 "Energy performance of buildings – Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads – Part 1: Calculation procedures" is carried out. The following descriptions on the calculation of heating and cooling demand is quoted from A Technical Manual for SBEM (p.51-, UK volume, 20 November 2015)

For space heating, the energy demand for each zone for each month is calculated according to:

$$Q_{NH}=Q_{L,H} - \eta_{G,H} \cdot Q_{G,H} \qquad (18)$$

where

Q_{NH}: building zone energy demandd for heating, in MJ

$Q_{L,H}$: total heat transfer (losses) for the heating mode, in MJ

$Q_{G,H}$: total heat sources (gains) for the heating mode, in MJ

$\eta_{G,H}$: gain utilization factor, which is a function of mainly the gain-loss ratio and the thermal inertia of the building

For space cooling, the energy demand for each zone for each month is calculated according to:

$$Q_{NC}=Q_{G,C} - \eta_{L,C} \cdot Q_{L,C} \qquad (19)$$

where

Q_{NC}: building zone energy need for cooling, in MJ

$Q_{G,C}$: total heat sources(gains) for the cooling mode, in MJ

$Q_{L,C}$: total heat transfer (losses) for the cooling mode, in MJ

$\eta_{L,C}$: utilization factor for heat losses, which is a function of mainly the loss-gain ratio and inertia of the building

The total heat transfer Q_L ($Q_{L,H}$, $Q_{L,C}$) is given by:

$$Q_L = Q_T + Q_V \qquad (20)$$

where

Q_T: the total heat transfer by transmission, in MJ

Q_V: the total heat transfer by ventilation, in MJ

The total heat sources Q_G ($Q_{G,H}$, $Q_{G,C}$) is given by:

$$Q_G = Q_i + Q_S \qquad (21)$$

where

Q_i: the sum of internal heat sources over the given period, in MJ

Q_S: the sum of solar heat sources over the given period, in MJ

The total heat transfer by transmission Q_T is given by:

$$Q_T = \Sigma_k\{H_{T,k} \cdot (\theta_i - \theta_{e,k})\} \cdot t \cdot f \qquad (22)$$

$$H_T = \Sigma_i A_i \cdot U_i + \Sigma_j l_j \cdot \Psi_j \qquad (23)$$

where

$H_{T,k}$: the heat transfer coefficient by transmission of element k to adjacent space(s), environment , or zone(s) in W/K;

θi: the internal temperature of the building zone (setpoint);

$\theta_{e,k}$: the external temperature (the monthly average temperature) of element k;

t: number of days in the month;

f: a factor for conversion from Wh to MJ;

A_i: the area of element i of the building envelope, in m^2;

Ui: the thermal transmittance (U-value) of element i of the building envelope, in $W/(m^2 \cdot K)$;

l_j: the length of linear thermal bridge k, in m;

Ψ_j: the thermal transmittance of linear thermal bridge k, in $W/(m \cdot K)$.

The heat transfer by ventilation is given by:

$$Q_V = H_v \cdot (\theta i - \theta_{e,}) \cdot n \cdot 0.0864 \qquad (24)$$

where

Q_V : the heat transfer by ventilation, in MJ/month

H_v: the ventilation heat loss coefficient, in W/K

θi: the internal temperature (the heating setpoint taken from the activity database for the activity zone)

$\theta_{e,}$: the external temperature (the monthly average temperature), in K

n: the number of days within a month.

$$H_v = \rho_a \cdot c_a \cdot u_v \cdot A \qquad (25)$$

where

H_v: the ventilation heat loss coefficient, in W/K;

$\rho_a \cdot c_a$: the air heat capacity per volume (1.2 kJ/m^{3}K);

u_v: the air flow rate through the conditioned space, in l/sm^{2}floor area, which is calculated as the total air flow rate due to infiltration and mechanical ventilation, which is reduced taking into account the efficiency of the heat recovery system. Only for heating energy demand, the air flow rate due to the natural ventilation is added;

A: the zone floor area, in m^2.

Intermittent heating is considered to be continuous heating with adjusted setpoint temperature, if the time constant of the building zone and the setpoint temperature variation between periods with different setpoint temperatures are within a certain range. If not, the energy demand for the intermittent heating is calculated by multiplying the energy demand for the continuous heating the dimensionless reduction factor as a function of the time constant of the building zone and the fraction of the number of hours in the month with a normal heating setpoint. On the contrary, the energy demand for cooling is calculated by multiplying the energy demand for the continuous cooling the dimensionless reduction factor as a function of the time constant of the building zone and the fraction of the number of days in the month with, at least during daytime, a normal cooling setpoint.

The annual heating and cooling energy demand for a given combination of heating, cooling and ventilation systems servicing different zones is the sum of the energy demands over the zones that are serviced by the same combination of systems;

$$Q_{NH,yr,zs} = \Sigma_z Q_{NH,yr,z} \quad \text{and} \quad Q_{NC,yr,zs} = \Sigma_z Q_{NC,yr,z} \tag{26}$$

where

$Q_{NH,yr,zs}$: the annual energy demand for heating for all building zones, zs, serviced by the same combination of systems, in MJ;

$Q_{NH,yr,z}$: the annual energy demand for heating for heating zone, z, serviced by the same combination of systems, in MJ;

$Q_{NC,yr,zs}$: the annual energy demand for cooling for all building zones, zs, serviced by the same combination of systems, in MJ;

$Q_{NC,yr,z}$: the annual energy demand for cooling for zone, z, serviced by the same combination of systems, in MJ.

Heating energy consumption is determined on a monthly basis for each HVAC system defined in the building. Having calculated the energy demand for heating in each zone of the building ($Q_{NH,yr}$) as described above, the heating energy demand for the HVAC system is the sum of the demands of all the zones serviced by that HVAC system (H_d in the following equation). The heating energy consumption for the HVAC system (H_e) is then calculated as follows:

$$H_e = H_d / SSEFF \tag{27}$$

where *SSEFF* is the system seasonal efficiency of the heating system, which is the ratio of the total heating need in zone(s) serviced by the HVAC system divided by the energy input into the heat generator(s).

The SSEFF takes account of the efficiency of the heat generator(s), thermal losses from pipework and duct work, and duct leakage, but does not take account of energy use for fans and pumps.

The building heating energy use will be the addition of the heating energy use of all the HVAC systems

included in the building.
If metering is applied, the heating energy use can be reduced by 5%.

Cooling energy consumption is also determined on a monthly basis for each HVAC system defined in the building. Having calculated the energy need for cooling in each zone of the building ($Q_{NC,yr,z}$) as described above, the cooling energy demand for the HVAC system is the sum of the demands of all the zones serviced by that HVAC system (C_d in the following equation). The cooling energy consumption for the HVAC system (C_e) is then calculated as follows:

$$C_e = C_d / SSEER \tag{28}$$

where *SSEER* is the system seasonal efficiency ratio of the cooling system, which is the ratio of the total heating need in zone(s) serviced by the HVAC system divided by the energy input into the cold generator(s).

The SSEER takes account of the efficiency of the cold generator(s), thermal gains to pipework and duct work, and duct leakage, but does not take account of energy consumption for fans and pumps.
The building cooling energy consumption will be the addition of the cooling energy use of all the HVAC systems included in the building.
If metering is applied, the cooling energy use can be reduced by 5%.

The pump auxiliary energy consumption for each zone is calculated by multiplying the pump power density in kWh/m^2 and the area of the zone in m^2. The pump power density for the actual building depends on the type of HVAC system and whether the pump has variable speed control. The pump power density can be determined as described in Table 24 and Table 25. The fan power for the actual building can be determined as described in Table 24.

Table 24 HVAC system type and usage of low temperature hot water (LTHW) and chilled water (CW), applicability of variable speed pumping, and equation to determine fan power density.

HVAC system type	Pump power	Variable speed pumping applicability	Fan power density
1. Central heating using water: radiators	LTHW only	Yes	-
2. Central heating using water: convectors	LTHW only	Yes	-
3. Central heating using water: floor heating	LTHW only	Yes	-
4. Central heating with air distribution	None	No	FPS_2
5. Other local room heater – fanned	None	No	-
6. Other local room heater – unfanned	None	No	-
7. Unflued radiant heater	None	No	-
8. Flued radiant heater	None	No	-
9. Multiburner radiant heaters	None	No	-
10. Flued forced-convection air heaters	None	No	-
11. Unflued forced-convection heaters	None	No	-
12. Single-duct VAV	Both LTHW and CHW	No	FPS_2
13. Dual-duct VAV	Both LTHW and CHW	No	FPS_2
14. Indoor packaged cabinet (VAV)	Both LTHW and CHW	Yes	FPS_1
15. Fan coil systems	Both LTHW and CHW	Yes	FPS_1
16. Induction system	Both LTHW and CHW	Yes	FPS_3
17. Constant volume system (fixed fresh air rate)	Both LTHW and CHW	No	FPS_2
18. Constant volume system (variable fresh air rate)	Both LTHW and CHW	No	FPS_2
19. Multizone (hot deck/cold deck)	Both LTHW and CHW	No	FPS_2
20. Terminal reheat (constant volume)	Both LTHW and CHW	No	FPS_2
21. Dual duct (constant volume)	Both LTHW and CHW	No	FPS_2
22. Chilled ceilings or passive chilled beams and displacement ventilation	Both LTHW and CHW	Yes	FPS_4
23. Active chilled beams	Both LTHW and CHW	Yes	FPS_3
24. Water loop heat pump	Both LTHW and CHW	No	FPS_2
25. Split or multi-split system	None	No	-
26. Single room cooling system	None	No	-

Note 1: LTHW and CHW mean Low Temperature Hot Water and Chilled Water, respectively.

Note 2: $FPS_1 = (FAR_{max} \cdot SFP_{central}) + (SCR \cdot SFP_{terminal})$

$FPS_2 = \max(FAR_{max}, SCR) \cdot SFP_{central}$

$FPS_3 = \max(SCR/5, FAR_{max}) \cdot SFP_{central}$

$FPS_4 = FAR_{max} \cdot SFP_{central}$

where

$SCR = \max(PSH, PSC) / (\rho \cdot C_p \cdot \Delta T)$

SCR: the space conditioning supply rate, in $l/s{\cdot}m^2$

FAR_{max}: the peak fresh air supply rate, in $l/s{\cdot}m^2$ that is set by the activity type

$SFP_{central}$: the specific fan power of central fan, in W/(L/s)

$SFP_{terminal}$: the specific fan power

PSH: the peak space heating need, in W/m^2

PSC: the peak space cooling need, in W/m^2

$\rho \cdot C_p$: $1.2 \cdot 1.018$ $kJ/m^3{\cdot}K$

$\Delta T = 8$ K

Table 25 Pump power density for actual building

Pump configuration	Pump power density (W/m²)	
	LTHW only	Both LTHW and CHW
Constant speed pumping	0.6	1.8
Variable speed pumping with differential sensor across pump	0.5	1.5
Variable speed pumping with differential sensor in the system	0.4	1.1
Variable speed pumping with multiple pressure sensors in the system	0.3	0.9

The SSEFF and SSEER are the energy efficiencies as a total system including the efficiencies of heat and cold generators, thermal losses and gains through pipework and ductwork, and duct leakage. SBEM offers the user a range of system types, and the system choice sets standard values for most of the mechanisms.

The user is required to input (or accept a default value for) the following items:

1) Heat source type, fuel type and the Effective Heat Generating Seasonal Efficiency for heating,
2) Generator type, fuel type, generator's seasonal efficiency ratio (SEER) and nominal efficiency ratio (EER) for cooling,
3) Heat recovery type and its seasonal efficiency,
4) Leakage class of ductwork and air handling unit,
5) Specific fan power and pump control,
6) Metering provision
7) Heat source type, fuel type and seasonal efficiency for bivalent system.

The Effective Heat Generating Seasonal Efficiency is calculated by adding the Heating Efficiency Credit, where applicable, to the Heat Generator Seasonal Efficiency. The Heat Generator Seasonal Efficiency is the ratio of the useful heat output to the energy input over the heating season.

In A Technical Manual for SBEM (UK volume, 20 November 2015), the following explanation is given for EN 15243:2007 entitled "Ventilation for buildings – Calculation of room temperatures and of load and energy for buildings with room conditioning systems"[12]:

"In EN 15243, the mechanisms are mapped against 20 or so types of HVAC systems to show which mechanisms may apply to which system types. Any compliant calculation procedure is required to declare which system types it claims to cover, and how it addresses each of the applicable mechanisms. The standard does not prescribe how each mechanism should be handled (although there are 'informative' suggestions). SBEM included all the mechanisms that were in the draft standard at the time SBEM was being developed."

5.6.4 Software tools available for use for Building Regulation compliance and Energy Performance Certification generation for buildings other than dwellings

Three main classes of software tool are available for use for Building Regulation compliance and Energy Performance Certification generation for buildings other than dwellings. The first is SBEM, which is

[12] EN 15243:2007 has been withdrawn and replaced by EN 16798-9:2017 and EN 16798-13:2017

considered to be the default, free tool. The second type is FI-SBEM , which includes a number of graphical interfaces to the SBEM engine. iSBEM is the freely available FI-SBEM interface, although other interfaces exist and must be approved for use. The third type are Dynamic Simulation Models (DSMs). These must also be approved and are applicable for any building unless an individual DSM's approval specifically excludes certain classes of building or building features. The test protocol for the DSMs, CIBSE TM33 "Tests for software accreditation and verification" was published in 2006 in response to the need for the UK regulators to have a mechanism for the technical accreditation of detailed thermal models as part of their formal approval for use in the National Calculation Methodology.

The purposes of TM33 are:
1) Technical accreditation of detailed thermal models as part of obtaining formal approval for their use in the National Calculation Methodology which describes additional steps needed for a tool to become approved for use in demonstrating compliance with the Building Regulations in England and Wales.
2) Verification that such programs produce results consistent with good practice as set out in the methods in the CIBSE guides.

For a tool to be accredited, the supplier of a detailed thermal model is required to show that their software meets the requirements of the tests described in sections 2 and 3 of TM33. In addition, the supplier is required to show that their software meets the requirements of BS EN ISO 13791: 2004 "Thermal performance of buildings. Calculation of internal temperatures in a room in summer without mechanical cooling. General criteria and validation procedures" or BS EN ISO 13792: 2004 "Thermal performance of buildings. Calculation of internal temperatures in a room in summer without mechanical cooling. Simplified methods". An overview of the tests contained in the sections 2 and 3 is shown in Table 26.

Table 26 List of tests necessary for accreditation of programs

Section in TM33	Title of test	Purpose of test checking;
2	Test G1: Database	material properties
	Test G2: Solar position	the position of the sun
	Test G3: Basic thermal calculations	thermal conductance for components and internal air temperature
	Test G4: Solar shading	shading fraction
	Test G5: Glazing properties	g-value and U-value for typical grazing configurations
	Test G6: Steady state heat loss from rooms	Room surface and air temperature, and heat loss
	Test G7: Annual cooling and heating demand	Heating and cooling needs
	Test G8: Overheating risk	Internal temperature without heating and cooling
	Test G9: Infiltration and ventilation	Air flow network calculation results
	Test G10: Air handling unit test	Heating and cooling needs, and fan energy use
3	Empirical validation test	Energy use for heating and maximum/minimum interior temperature by the comparison with experimental results

5.7 United States of America: ASHRAE Standard 90.1 and EnergyPlus

5.7.1 Building Energy Codes in US

In the United States, energy codes are a subset of building codes, which establish baseline requirements and govern building construction. It is recognized that the model building energy codes are ASHRAE Standard 90.1 for commercial (non-residential) and multi-family high-rise buildings, and ICC (International Code Council) IECC (International Energy Conservation Code) for low-rise residential buildings[*)]. Buildings containing both residential and commercial spaces are generally considered separately with respect to compliance with model energy codes, even though they can be submitted under a single building permit.

As for ASHRAE Standard 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings, proposed changes are developed as addenda to the current edition of the standard. When approved, the changes are published as separate addenda. Every three years those addenda are aggregated and incorporated into a new edition of Standard 90.1.

Title III of the Energy Conservation and Production Act of 1976, as amended gives the legal basis of the building energy code. The performance standards is defined in the Act as “an energy conservation goal or goals to be met without specification of the methods, materials, and processes to be employed in achieving that goal or goals, but including statements of the requirements, criteria and evaluation methods to be used, and any necessary commentary”. The Act requires that whenever a new edition of Standard 90.1 is published, the U.S. Department of Energy (US DOE) must issue a determination whether the revised code would improve energy efficiency in commercial buildings. States then have two years to certify to the US DOE that they have reviewed and updated the energy provisions of their state energy to meet or exceed the revised edition of Standard 90.1.

5.7.2 Demonstration of Compliance for Commercial Buildings

There are several ways to show compliance. Table 27 shows the main three compliance approaches for commercial buildings.

Table 27 The Main Three Approaches to Show Compliance for Commercial Buildings

Approach	Description	Compliance Tool(s)
Prescriptive Approach	For the building envelope, the minimum R-value or maximum U-factor requirements for each building component. For mechanical systems and equipment, the minimum required equipment efficiencies. This approach is quick and easy to use, but may be somewhat restrictive because the requirements typically are based on worst-case assumption for parameters not prescribed.	ASHRAE Standard 90.1 and the IECC contain information tables that can be applied directly to demonstrate compliance.
System Trade-off Approach	This approach allows trading enhanced energy efficiency in one component against decreased energy efficiency in another components. The trade-offs typically occur within major building systems; envelope, lighting, or mechanical. Only trade-off allowed for mechanical systems and equipment is found in Chapter 8 of the IECC. Higher cooling system efficiency can be traded off against a requirement for an economizer (a cooling method by inducing outdoor air).	A free-of-charge compliance software called "COMcheck" is supplied by DOE. Through inputs of a building project's features, a user can generate and print compliance certificates for each major building system.
Whole Building Performance Approach	A whole building performance approach uses energy simulation to demonstrate that a proposed building design performs as well as a baseline design that just meets the prescriptive requirements of the energy code. For both the IECC and Standard 90.1, energy cost is the metric used for the comparison. This approach allows more flexibility but requires more effort.	DOE's Building Technologies Program maintains a list of building energy software tools approved for submitting energy performance calculations for the 179D tax credit. Many code jurisdictions reference this list.

5.7.3 Structure of ASHRAE Standard 90.1

Table 28 shows contents of ASHRAE Standard 90.1-2019. Among the sections and appendices, Sections 5, 6, 11 and Normative Appendix G are most relevant to energy use for HVAC systems. Possible compliance approaches are prescribed in Section 4, where the following three approaches ((a), (b) and (c)) and common requirements ((1), (2), (3) and (4)) for those approaches are prescribed.

a) Prescriptive requirements for "Building Envelope" (Section 5), "Heating, Ventilating, and Air Conditioning" (Section 6), "Service Water Heating" (Section 7), "Power" (Section 8), "Lighting" (Section 9) and "Other Equipment" (Section 10)

b) "Energy Cost Budget Method" (Section 11). This approach provides more flexibility by allowing a designer to trade off compliance by not meeting some prescriptive requirements if the impact can be offset by exceeding other prescriptive requirements. Compliance is demonstrated using computer simulation to compare a proposed building design to a code compliant reference building design commonly referred to as a baseline. The baseline is essentially of clone of the proposed design with most of the building component adjusted to “just meet” current prescriptive requirements. The proposed design energy cost must be no greater than the baseline energy cost for the design to comply.

c) “Performance Rating Method” (Normative Appendix G). This approach is similar to the Energy Cost Budget (ECB) Method in that it allows trade-offs by comparing a proposed building energy cost to a reference building energy cost. However, there are two main differences between Appendix G and ECB. Appendix G uses a more independent baseline where many of the characteristics of the baseline design are based on standard practice instead of following the proposed design. For example, window area and HVAC system type are based on the type of building and location. This means credit is available not only for exceeding prescriptive requirements in the code, but also for exceeding standard practice that is not regulated by the code. For example, in Appendix G credit is available for strategies not credited in EBC such as optimized window area and orientation, selection of more efficient HVAC and service water heating equipment, right sizing HVAC equipment, efficient use of thermal mass, etc. In addition, Appendix G uses a stable baseline approach with efficiency levels set at values that are not intended to be updated with each new edition of the code. Instead, the proposed building energy performance needs to exceed that of the baseline by an amount commensurate with the code year being evaluated. As each new version of a code gets more stringent, the proposed building performance needs to exceed the baseline by an increased amount. The metric used is called the Performance Cost Index (PCI), which is simply the annual energy cost of a proposed building design divided by the baseline energy cost. Since the baseline is stable, for compliance, the PCI must be less than a Performance Cost Index Target, which is specific for each edition of the code, the type of building (office verses retail, etc.), the climate location, and the ratio of energy use that is regulated by Standard 90.1 to the total energy use of the evaluated building.

The common requirements for the above three compliance approaches are as follows:

1) Each section (“Building Envelope” (Section 5), “Heating, Ventilating, and Air Conditioning” (Section 6), “Service Water Heating” (Section 7), “Power” (Section 8), “Lighting” (Section 9) and “Other Equipment” (Section 10) includes a number of provisions that must be adhered to regardless of which of the above three paths is chosen. For example, requirements for envelope air sealing, lighting controls, and HVAC equipment efficiency are all mandatory and cannot be traded off against improvements in other areas.

2) Compliance documents shall show all the pertinent data and features of the building, equipment, and systems in sufficient detail to permit a determination of compliance by the building officials (Section 4.2.2).

3) Materials and equipment shall be labelled in a manner that will allow for a determination of their compliance with the applicable provisions of this standard (Section 4.2.3).

4) All building construction, additions, or alterations work subject to the provisions of this standard shall

remain accessible and exposed for inspection processes until approved in accordance with the procedures specified by the building official (Section 4.2.4).

5) Verification or functional performance testing (*FPT*) to conform compliance with required provisions of this standard shall be performed on building systems, controls, and the building envelope, as required in relevant sections of this standard (Section 4.2.5).

Table 28 Sections of ASHRAE Standard 90.1-2019

Section 1	Purpose
Section 2	Scope
Section 3	Definition, Abbreviations, and Acronyms
Section 4	Administration and Enforcement
Section 5	Building Envelope
Section 6	Heating, Ventilating, and Air Conditioning
Section 7	Service Water Heating
Section 8	Power
Section 9	Lighting
Section 10	Other Equipment
Section 11	Energy Cost Budget Method
Section 12	Normative References
Normative Appendix A	Rated R-Value of insulation and Assembly U-Factor, C-Factor, and F-Factor Determinations
Informative Appendix B	(Retained for Future Use)
Normative Appendix C	Methodology for Building Envelope Trade-Off Option in Section 5.6
Informative Appendix D	(Retained for Future Use)
Informative Appendix E	Informative References
Informative Appendix F	U.S. Department of Energy Minimum Energy Efficiency Requirements
Normative Appendix G	Performance Rating Method
Informative Appendix H	Additional Guidance for Verification, Testing, and Commissioning
Informative Appendix I	Addenda Description Information
Annex 1	Reference Standard Reproduction Annex – ASHRAE Standard 169

5.7.4 Compliance approach (a), Prescriptive requirements for building envelope and equipment

There is an approach in ASHRAE Standard 90.1 to comply with the standard by fulfilling prescriptive requirements. The requirements are made for “Building Envelope” (Section 5), “Heating, Ventilating, and Air Conditioning” (Section 6), “Service Water Heating” (Section 7), “Power” (section 8), “Lighting” (Section 9), and “Other Equipment” (Section 10), as already mentioned in 5.6.3.

For the building envelope, the following requirements are prescribed for each of climate zones 1 to 8 (Section 5.5):

・Insulation related parameters for roofs, walls above grade and floors (R-value and U-factor),
・Insulation related parameters for walls below grade (C-factor) and slab-on-grade floor (F-factor),
・Limit of vertical fenestration area compared with wall area and horizontal fenestration compared to roof

area,
・Characteristics of fenestration (U-factor, SHGC and ratio of Visual Transmittance to SHGC),
・Minimum areas of skylights and daylit areas for large, high-bay spaces,
・The common criteria of above parameters for non-residential buildings are used for different type of buildings, although there are relaxed requirements for semi-heated spaces,
・The requirement for air leakage control is also included by sealing windows and doors, and requiring vestibules in many buildings. The standard also prescribes the maximum air leakage measured under pressure difference of 75Pa with the criterion of 2.0 L/s/m^2 (Section 5.4.3.1), with the exception for complying with the continuous air barrier design and installation verification program (Section 5.9.1.2).

For heating, ventilating and air conditioning, the following requirements are prescribed:
・Minimum equipment efficiencies of heating and cooling sources and commercial refrigeration systems listed in Table 29 (Section 6.4.1.1),
・Sizing systems and equipment by heating and cooling load calculation in accordance with ASHRAE/ACCA Standard 183, and sizing pumps by pump differential pressure calculation in the critical circuit at design conditions (Section 6.4.2),
・Control of heating, ventilating, and air conditioning systems (Section 6.4.3),
・Duct and piping insulation, and duct sealing and leakage tests (Sections 6.4.4.1 and 6.4.4.2),
・Limitation on simultaneous heating and cooling (Section 6.5.2),
・Limitation of nameplate kilowatts or input of motors for fan system in comparison with maximum design supply flow rate (Section 6.5.3.1),
・VAV static pressure measurement, static pressure set-point reset control, supply air temperature reset control, and ventilation design to reduce heating and cooling load (Sections 6.5.3.2, 6.5.3.5 and 6.5.3.7),
・Hydronic variable flow system control, and chilled- and hot water temperature reset control (Sections 6.5.4.2 and 6.5.4.4),
・Determination of pipe sizing and chilled-water coil selection (Sections 6.5.4.6 and 6.5.4.7),
・Fan speed control of heat-rejection equipment (e.g., air-cooled condensers, cooling towers) (Section 6.5.5),
・Requirement of exhaust air energy recovery depending on climate zones and outdoor air intake quantity (Section 6.5.6.1)

Table 29 Equipment of which minimum efficiencies are prescribed in Section 6.4 of 90.1-2019

Type of heat source equipment	Index and testing standard
1. Electrically operated unitary air conditioners and condensing units	SCOP (AHRI 210/240), COP or ICOP (AHRI 340/360 or AHRI 365)
2. Electrically operated air-cooled unitary heat pumps	SCOP (AHRI 210/240), COP or ICOP (AHRI 340/360)
3. Water-chilling packages (including electrically operated chillers and absorption chiller)	FL (full-load) and IPLV.SI (part-load) (AHRI 551/591 or AHRI 560 for absorption chillers)
4. Electrically operated packaged terminal air conditioners, packaged terminal heat pumps, single-package vertical air conditioners, single package vertical heat pumps, room air conditioners, and room air-conditioner heat pumps	COP (AHRI 310/380 for package terminal and AHRI 390 for single package vertical), CCOP (ANSI/AHAM RAC-1)
5. Warm-air furnaces and combination warm-air furnaces/air-conditioning units, warm-air duct furnaces, and unit heaters	AFUE, annual fuel utilization efficiency (DOE Title 10 CFR 430, ANSI Z21.47 or UL727), E_t (ANSI Z21.47), E_c (ANSI Z83.8 or UL 731)
6. Gas- and Oil-fired boilers	AFUE (DOE Title 10 CFR 430) or E_t, E_c (10 CFR 431.86)
7. Heat rejection equipment including cooling towers, fan dry coolers, air cooled condensers	L/s/kW with test conditions of water and air temperature (CTI ATC-105 and CTI STD-201 RS), COP (CTI ATC-106 or AHRI 460)
8. Electrically operated variable-refrigerant-flow air conditioners	SCOP, COP or ICOP (AHRI 1230)
9. Electrically operated variable-refrigerant-flow and applied heat pumps	SCOP, COP or ICOP (AHRI 1230)
10. Floor-mounted air conditioners and condensing units serving computer rooms	COP (AHRI 1361 or AHRI 1360)
11. Commercial refrigerators, commercial freezers, and refrigeration	Maximum daily energy consumption in kWh/day (AHRI 1201)
12. Vapor compression based indoor pool dehumidifiers	MRE (AHRI 911)
13. Electrically operated DX-DOAS units, single-package remote condenser	ISMRE or ISCOP (AHRI 921)
14. Electrically operated water source heat pumps	COP (ISO 13256-1 or -2)
15. Heat-pump and heat recovery chiller package	FL (full-load) and IPLV.SI (part-load) (AHRI 551/591)
16. Ceiling-mounted computer-room air conditioners	COP (AHRI 1360 or AHRI 1361)
17. Walk-in cooler and freezer	Maximum energy consumption in kWh/day (DOE Title 10 CFR 431)
18. Walk-in cooler and freezer refrigeration system	AWEF, minimum annual walk-in energy factor (AHRI 1251)

5.7.5 Compliance approach (b), "Energy Cost Budget Method"

The compliance approach (b), "Energy Cost Budget Method" requires the use of a computer-based simulation program for the analysis of energy consumption in buildings. The simulation program shall be approved by the adopting authority and shall, at a minimum, have the ability to explicitly model all of the items listed in Table 30. The simulation program also shall be capable of performing design load calculations to determine required HVAC equipment capacities and air and water flow rates in accordance with generally accepted engineering standards and handbooks.

Another important requirement for simulation programs used for the compliance approach (b) is that they are tested in accordance with ASHRAE Standard 140, Standard Method for Test for the Evaluation of Building Energy Analysis Computer Programs and the test results must be made publically available. This requirement is also applied to the simulation program used for the compliance approach (c), which will be introduced later.

Table 30 Requirement for simulation programs used in compliance approaches (b)

a.	8760 hours per year
b.	Hourly variation in occupancy, lighting power, miscellaneous equipment power, thermostat set points, and HVAC system operation, defined separately for each day of the week and holidays
c.	Thermal mass effects
d.	Ten or more thermal zones
e.	Part-load performance curves for mechanical equipment
f.	Capacity and efficiency correction curves for mechanical heating and mechanical cooling equipment
g.	Air-side economizer and fluid economizer with integrated control
h.	The budget building design characteristics for b) and the baseline building design characteristics for c)

The performances of proposed and baseline building are quantified using the same purchased energy rates. The former and the latter are called "design energy cost (DEC)" and "energy cost budget (ECB)", respectively.

In the energy and energy cost calculation of the design energy cost for the proposed design, all components of the building envelope, all lighting system components and controls, the HVAC system type and all related performance parameters, and the service water-system type and all related performance parameters shall be modelled as shown on design documents. In addition, all other end use load components including receptacle, motor and process loads, parking garage ventilation fans, swimming pool heaters and pumps, elevators and escalators, and cooking equipment shall be modeled based on the design documents or estimated based on the building type. Major parts of the prescriptive requirements from Section 5 (such as U-factor or R-value, fenestration area, SHGC), Section 6 (such as fan motor size, VAV controls, hydronic variable flow controls, pipe size, exhaust air energy recover) are not required for the proposed design.

On the other hand, in the energy cost budget or baseline calculation, for the building envelope, the minimum U-factor for opaque assemblies such as roof, floors and walls, and the fenestration area and thermal characteristics are assumed to be equal to the criteria in mandatory and prescriptive provisions in the compliance approach (a). The HVAC system in the energy cost budget is determined from Table 31, depending on the HVAC system type in the proposed design. System type features in Table 31 are described in Table 32. For example, if a proposed building design, which is non-residential, has electric water cooled chillers, and hot water from natural gas fired boilers for space heating, the HVAC system of the energy cost budget building is assumed to be System 2; multi-zone variable air volume fan systems with hot water reheat from gas-fired boilers, and electrically operated water cooled chillers. The number and type of the chillers is based on the chilled water plant capcacity. The equipment capacities for the cost budget building are sized based on its sizing runs and the proportion between the capacities in the design energy cost building based on its sizing runs and its capacities as shown on architectural drawings. All HVAC and service water-heating equipment in the budget energy cost building are modelled at the minimum efficiency levels in accordance with Sections 6.4 and 7.4.

In the VAV fan control for System 1 to System 4 for the energy cost budget building, the supply, return, or relief fan motor is modelled assuming a variable speed drive and meets the VAV fan part-load performance curve shown in Figure 11. If the design energy cost building has a direct digital control (DDC) system at the zone level, static pressure set-point reset based on zone requirements is modelled for the energy cost budget building.

Table 31 HVAC systems to be assumed in energy cost budget calculation in the compliance approach b) (reproduced based on Figure 11.5.2 of ASHRAE Standard 90.1-2019, only for non-residential buildings)

HVAC System Type of Design Energy Cost Building			HVAC System Type of Energy Cost Budget Building	
Condenser Cooling Source	Heating System Classification		Single Zone Non-residential HVAC System	Other Non-residential HVAC System
Water/Ground	Electric Resistance	→	System 5	System 1
	Heat Pump	→	System 6	System 6
	Fossil Fuel	→	System 7	System 2
Air/None	Electric Resistance	→	System 9	System 3
	Heat Pump	→	System 9	System 3
	Fossil Fuel	→	System 11	System 4

Table 32 HVAC Systems assumed in Energy Cost Budget Building (only for non-residential buildings)

System No.	System Type	Fan Control	Cooling Type	Heating Type
System 1	VAV with parallel fan-powered boxes	VAV	Chilled water	Electric resistance
System 2	VAV with reheat	VAV	Chilled water	Hot-water fossil fuel boiler
System 3	Packaged VAV with parallel fan-powered boxes	VAV	Direct expansion	Electric resistance
System 4	Packaged VAV with reheat	VAV	Direct expansion	Hot-water fossil fuel boiler
System 5	Two-pipe fan coil	Single- or two-speed fan	Chilled water	Electric resistance
System 6	Water-source heat pump	Single- or two-speed fan	Direct expansion	Electric heat pump and boiler
System 7	Four-pipe fan-coil	Single- or two-speed fan	Direct expansion	Hot-water fossil fuel boiler
System 9	Packaged rooftop heat pump	Single- or two-speed fan	Direct expansion	Electric heat pump
System 11	Packaged rooftop air conditioner	Single- or two-speed fan	Direct expansion	Fossil fuel furnace

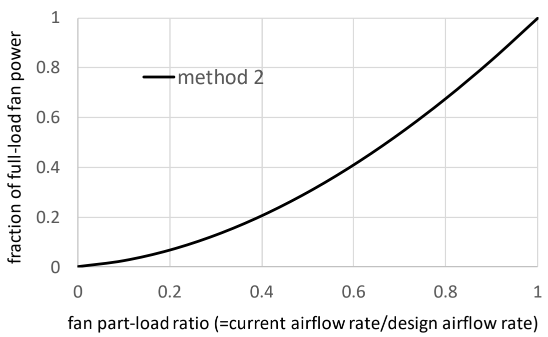


Figure 10 Part-load performance for VAV fan systems (drawn based on Table G3.1.3.15 of ASHRAE Standard 90.1-2019)

5.7.6 Compliance approach (c), "Performance Rating Method"

This compliance approach also needs a computer-based simulation program, and the requirements for the simulation programs (requirements (a) to (f) in Table X4 plus two additional requirements as shown in Table 33) are applied. In the compliance approach (c), conditions of energy calculations and judgement criteria of compliance are different from the approach (b).

Table 33 Requirements for simulation programs used in compliance approach (c)

a.	8760 hours per year
b.	Hourly variation in occupancy, lighting power, miscellaneous equipment power, thermostat set points, and HVAC system operation, defined separately for each day of the week and holidays
c.	Thermal mass effects
d.	Ten or more thermal zones
e.	Part-load performance curves for mechanical equipment
f.	Capacity and efficiency correction curves for mechanical heating and mechanical cooling equipment
g.	Air economizers with integrated control
h.	Baseline building design characteristics specified in Appendix G of ASHREA Standard 90.1

The Performance Cost Index (PCI) shall be calculated based on the simulated energy costs for the evaluated building and the baseline building, and compared with the Performance Cost Index Target (PCI_t). These two indices are defined as follows:

$$\mathrm{PCI} = \frac{\text{Proposed building performance}}{\text{Baseline building performance}} \tag{29}$$

$$\mathrm{PCI_t} = \frac{[\mathrm{BBUEC} + (\mathrm{BPF} \times \mathrm{BBREC})]}{\mathrm{BBP}} \tag{30}$$

where

BBUEC=baseline building unregulated energy cost, which is for receptacle and process load.

BPF=building performance factor, which is a required reduction rate of regulated cost for each combination of climate zone and building area type. BPF values are given in Table 4.2.1.1 of the standard, and range between 0.36 and 0.76.

BBREC=baseline building regulated energy cost, which is for HVAC, lighting, service water-heating, distribution transformers, elevators, and refrigeration.
BBP=baseline building performance.

This compliance approach also uses energy cost as evaluation basis.
In the energy and energy cost calculations for the proposed building performance for this compliance approach (c), conditions of calculation are similar to the compliance approach (b), except for the condition for infiltration. Infiltration shall be modelled for each simulation time step by using air leakage rate of the building envelope (L/s/m^2) at a fixed pressure differential of 75Pa, I_{75Pa}. If the measurement is not carried out, but verification of the design and installation of the continuous air barrier is determined by an independent third party as shown in Section 5.9.1.2, I_{75Pa} shall be 3.0 L/s/m^2.
On the other hand, in the energy and energy cost calculations for the baseline building performance, different conditions from the compliance approach (b) are assumed as follows:
・The assumptions on U-factor or R-value and other factors for insulation of opaque parts, and on the area, U-factor, SHGC and other thermal performance of fenestration, are less stringent than the requirements in Section 5, which are the assumptions for the energy cost budget building in the compliance approach (b). These assumptions for the baseline building are the same level of the requirements for the building envelope in ASHRAE Standard 90.1-2004 (the stable baseline described in Section 5.6.3). This less stringency is relevant to the building performance factor (BPF) has been introduced to determine the Performance Cost Index Target (PCI_t).
・Lighting power requirements and lighting control requirements are also less stringent than those in Section 9 for a similar reason as described above for envelope components. They are also based on the requirements from Standard 90.1-2004 and the difference is accounted for in the BPFs.
・The HVAC system types in the baseline building are assumed according to the building type, number of floors, gross conditioned area, and climate zone of the proposed building design, as shown in Table 34. The HVAC system types are described in Table 35.

Table 34 HVAC system types assumed in the baseline building for the compliance approach (c)

Building Type, Number of Floors, and Gross Conditioned Floor Area	Climate Zones 3B, 3C, and 4 to 8	Climate Zones 0 to 3A
Public assembly < 11,000 m^2	System 3 – PSZ-AC	System 4 – PSZ-HP
Public assembly >= 11,000 m^2	System 12 – SZ-CV-HW	System 13 – SZ-CV-ER
Heated only storage	System 9 – Heating and ventilation	System 10 – Heating and ventilation
Retail and 2 floors or fewer	System 3 – PSZ-AC	System 4 – PSZ-HP
Other nonresidential and 3 floors or fewer and <2300m^2	System 3 – PSZ-AC	System 4 – PSZ-HP
Other nonresidential and 4 or 5 floors and <2300 m^2 or 5 floors or fewer and 2300 m^2 to 14,000 m^2	System 5 – Packaged VAV with reheat	System 6 – Packaged VAV with PFP boxes
Other nonresidential and more than 5 floors or >14,000 m^2	System 7 – VAV with reheat	System 8 – VAV with PFP boxes

Table 35 Baseline HVAC system descriptions for the compliance approach (c) (extracted only systems for non-residential buildings)

System No.	System Type	Fan Control	Cooling Type	Heating Type
3. PSZ-AC	Packaged rooftop air conditioner	Constant volume	Direct expansion	Fossil fuel furnace
4. PSZ-HP	Packaged rooftop heat pump	Constant volume	Direct expansion	Electric heat pump
5. Packaged VAV with reheat	Packaged rooftop VAV with reheat	VAV	Direct expansion	Hot-water fossil fuel boiler
6. Packaged VAV with PFP boxes	Packaged rooftop VAV with parallel fan-powered boxes and reheat	VAV	Direct expansion	Electric resistance
7. VAV with reheat	VAV with reheat	VAV	Chilled water	Hot-water fossil fuel boiler
8. VAV with PFP boxes	VAV with parallel fan-powered boxes and reheat	VAV	Chilled water	Electric resistance
9. Heating and ventilation	Warm air furnace, gas fired	Constant volume	None	Fossil fuel furnace
10. Heating and ventilation	Warm air furnace, electric	Constant volume	None	Electric resistance
12. SZ-CV-HW	Single-zone system	Constant volume	Chilled water	Hot-water fossil fuel boiler
13. SZ-CV-ER	Single-zone system	Constant volume	Chilled water	Electric resistance

The following highlights some of the baseline HVAC systems requirements:

・All HVAC equipment in the baseline building design is modelled at the minimum efficiency levels, which are not so stringent as the minimum efficiency requirement of the current standard 90.1-2019 (Section 6, Table 6.8.1-1 to Table 6.8.1-8). This less stringency than the current standard prescriptive requirements are also relevant to the building performance factor (BPF), which is between 0.36 and 0.76 and multiplied to determine the PCI_t.

・System coil and equipment capacities for the baseline building design are based on sizing runs for four orientations (actual orientation, +90, +180 and +270 degrees), and on design days developed using heating design temperature, cooling design temperature, and cooling we-bulb temperature. System coil capacities are oversized at the fixed ratios, which are 1.15 for cooling and 1.25 for heating.

・System design supply airflow rates for the baseline building design for System types except for System types 9 and 10 are based on a supply-air-to-room temperature set-point difference of 11°C or the minimum outdoor airflow rate and the like. If the return or relief fans are specified in the proposed design, the baseline building design is modelled with such fans sized for the baseline building supply fan airflow rate less the minimum outdoor air, or 90% of the supply fan airflow rate, whichever is larger.

・For System types 3 through 8, 12 and 13 shown in Tables 34 and 35, integrated air economizer control, which intakes mechanically outdoor air to reduce cooling load, is included in the baseline building design in climate zones 2B, 3B, 3C, 4B, 4C, 5A, 5B, 5C, 6A, 6B, 7 and 8. Individual fan systems, of which capacities are not less than 2400 L/s and outdoor air supply rates are not less than 70% of the capacities, are assumed to have an energy recovery system with 50% enthalpy recovery ratio in the baseline building design.

5.7.7 EnergyPlus

5.7.7.1 Energy Needs (Heating and Cooling Loads) Calculation

EnergyPlus has its roots in both the BLAST and DOE-2 program. BLAST (Building Loads Analysis and System Thermodynamics) and DOE-2 were both developed and released in the late 1970s and early 1980s as energy and load simulation tools. BLAST was developed by the Construction Engineering Research Laboratory (CERL) and the University of Illinois while DOE-2 was developed by Berkeley Lab and many others. In the late 1990s, concern about limitations of BLAST, DOE-2 and IP issue of DOE-2, as well as difficulty in maintaining the old code bases prompted combining the development efforts for a new program called EnergyPlus.

EnergyPlus calculates the heating and cooling loads, indoor environment conditions, and equipment operations throughout a secondary HVAC system and coil loads, and the energy consumption of primary plant equipment. It is intended to be the simulation engine around which a third-party interface can be wrapped. When using EnergyPlus for demonstrating compliance with ASHRAE Standard 90.1 through the approaches (b) or (c), an appropriate interface is usually used in order to choose models in EnergyPlus and parameters for the models, which are required to do the simulation according to ASHRAE Standard 90.1.

The following description on EnergyPlus, as the representative building energy calculation methodology in US, is based mainly on;

Engineering Reference, Energyplus™ Version 9.2.0 Documentation, U.S. Department of Energy, September 27, 2019, and
Input Output Reference, Energyplus™ Version 9.2.0 Documentation, U.S. Department of Energy, September 27, 2019.

EnergyPlus uses a dynamic method for calculating heat conduction through the walls. The most basic time series solution is the response factor equation which relates the heat flux at one surface of an element in the envelope to an infinite series of temperature histories at both sides of the element as shown by the following equation:

$$q''_{ko}(t) = \sum_{j=0}^{\infty} X_j \, T_{o,t-j\delta} - \sum_{j=0}^{\infty} Y_j \, T_{i,t-j\delta} \qquad (31)$$

where $q''_{ko}(t)$ is the outside heat flux at time step t, T is temperature, i means the inside surface of this building element, o means the outside of the element, X and Y are the response factors. By the response factors, the delay of the heat conduction due to the thermal mass of the building element can be taken into consideration.

The method to solve the above equation used by EnergyPlus is shown by the following equation containing conduction transfer functions (CTFs):

$$q''_{ko}(t) = -Y_0 T_{i,t} - \sum_{j=1}^{nz} Y_j \, T_{i,t-j\delta} + X_0 T_{o,t} + \sum_{j=1}^{nz} X_j \, T_{o,t-j\delta} + \sum_{j=1}^{nq} \Phi_j \, q''_{ko,t-j\delta} \qquad (32)$$

where X_j is the outside CTF coefficient, j=0, 1, ···, nz. Y_j is the cross CTF coefficient, j=0, 1, ···, nz. Z_j is the inside CTF coefficient, j=0, 1, ···, nz. Φ_j is the flux CTF coefficient, j=0, 1, ···, nz. $q''_{ko}(t)$ is the conduction heat flux on outside surface at time step t. The basic method used in EnergyPlus for CTF calculation is known as the state space method. More detailed information including the overall air and heat balance in zones is given in the above-mentioned Engineering Reference (Chapter 3.1) and in ASHRAE HANDBOOK Fundamentals (in 2013, Chapter 18 "Heat Balance Method").

5.7.7.2 Calculation of Energy Use by Heat Sources

In general, EnergyPlus represents HVAC equipment at various levels of detail and users can choose a particular model considering the complexity and available data for their simulation use case. The part-load performance of mechanical equipment, which is one of the requirements from ASHRAE Standard 90.1 listed in Table 30 and Table 34, is taken into consideration in EnergyPlus as shown in the following examples for electric chillers, variable refrigerant flow equipment and hot water boilers.

Electric chillers based on fluid temperature difference

Power consumption (P) of an electric chiller is calculated by the following equation:

$$P\ (W) = \frac{Nominal\ capacity\ (W)}{Nominal\ COP} \times ACR \times FFLP \times FLPR \quad (33)$$

where ACR is the ratio of available capacity to nominal capacity as a function of temperature condition, $FFLP$ is the fraction of the full load power consumption as a function of the part load ratio, and $FLPR$ is the full load power ratio as a function of ACR.

The above-mentioned three functions are defined as follows:

(i) ACR

$$ACR = A_1 + A_2 \Delta T_{chiller} + A_3 \Delta T_{Chiller}^2 \quad (34)$$

$$\Delta T_{chiller} = \frac{T_{cond,in} - T_{cond,in,design}}{C_{temp}} - \left(T_{evap,out} - T_{evap,out,design}\right) \quad (35)$$

$$C_{temp} = \frac{T_{cond,in,required} - T_{cond,in,rated}}{T_{evap,out,required} - T_{evap,out,rated}} \quad (36)$$

where:

$T_{cond,in}$ is the water or air temperature entering the condenser,

$T_{cond,in,design}$ is the design water or air temperature entering the condenser,

$T_{evap,out}$ is the water temperature leaving the evaporator,

$T_{evap,out,design}$ is the design water temperature leaving the evaporator,

$T_{cond,in,required}$ is the required water or air temperature entering the condenser, to maintain rated capacity,

$T_{cond,in,rated}$ is the rated water or air temperature entering the condenser,

$T_{evap,out,required}$ is the required water temperature leaving the evaporator, to maintain rated capacity,

$T_{evap,out,rated}$ is the rated water temperature leaving the evaporator, and

A_1, A_2, A_3 are the coefficients of the Capacity Ratio Curve.

(ii) $FFLP$

$$FFLP = B_1 + B_2 PLR + B_3 PLR^2 \quad (37)$$

where PLR is the part load ratio defined as the ratio of current load to available capacity, and B_1, B_2, B_3

are the coefficients of the Full Load Ratio Curve.

(iii) $FLPR$

$$FLPR = C_1 + C_2ACR + C_3ACR^2 \tag{38}$$

where C_1, C_2, C_3 are the coefficients of the Power Ratio Curve.

Electric Chiller Model Based on Condenser Entering Temperature (object name Chiller:Electric:EIR)

This model simulates the performance and the power consumption of electric liquid chillers, such as reciprocating liquid chillers, centrifugal liquid chillers and screw liquid chillers. It also models the power consumption of condenser fans if modeling an air-cooler or evaporatively-cooled condenser. This model does not simulate the thermal performance or the power consumption of associated pumps or cooling towers. Power consumption ($P_{chiller}$) of an electric liquid chiller is calculated by the following equation:

$$P_{chiller}(W) = \frac{\dot{Q}_{ref}}{COP_{ref}} \times CFT \times EIRFT \times EIRPLR \times CCR \tag{39}$$

where $\dot{Q}_{ref}$ is the chiller capacity at reference conditions for temperature and flow rates, COP_{ref} is the reference coefficient of performance, CFT is the cooling capacity factor as a function of temperature curve, $EIRFT$ is the energy input to cooling output factor as a function of temperature curve, $EIRPLR$ is the energy input to cooling output as a function of part-load ratio (PLR), and CCR is the chiller cycling ratio, which is the coefficient to determine the power consumption below the minimum part load ratio.

$$CFT = a_1 + a_2(T_{cw,ls}) + a_3(T_{cw,ls})^2 + a_4(T_{cond,e}) + a_5(T_{cond,e})^2 + a_6(T_{cw,ls})(T_{cond,e}) \tag{40}$$

$$EIRFT = b_1 + b_2(T_{cw,ls}) + b_3(T_{cw,ls})^2 + b_4(T_{cond,e}) + b_5(T_{cond,e})^2 + b_6(T_{cw,ls})(T_{cond,e}) \tag{41}$$

$$EIRPLR = c_1 + c_2(PLR) + c_3(PLR)^2 \tag{42}$$

$$CCR = \min\left(\frac{PLR}{PLR_{min}}, 1.0\right) \tag{43}$$

where $T_{cw,ls}$ is the leaving chilled water setpoint temperature (°C), $T_{cond,e}$ is the entering condenser fluid temperature (°C), PLR is the part-load ratio = (cooling load) / (chiller's available cooling capacity), and PLR_{min} is the minimum part load ratio, below which the chiller cycles on and off to meet very small loads and the power consumption during the on cycle is the same as when the chiller is operating at the minimum part load ratio.

The performance curves for more than 160 chillers, including the default curves for reciprocating and centrifugal chillers are provided in the EnergyPlus Reference Datasets (Chillers.idf), which can be obtained when users download EnergyPlus. The performance curves were developed from information collected over a 10-year period from 1991 to 2001.

According to the descriptions[13] of the model, EER (COP) values defined in AHRI 550/590 are calculated

[13] See "14.3.9.4 Standard Rating (Integrated Part Load Value)" in Engineering Reference (pp.774-778).

at the various load capacity points (100%, 75%, 50% and 25% part-load ratios) by using the equations (39) to (43). This means indirectly that the curves (40) to (42) are obtained in the same test method prescribed in AHRI 550/590, even though the test method to be followed to obtain coefficients in the equations and curves is not directly prescribed in any documents for EnergyPlus.

Variable Refrigerant Flow Heat Pumps

A Variable Refrigerant Flow (VRF) Heat Pump is an air-conditioning system that varies the refrigerant flow rate using variable speed compressor(s) in the outdoor unit, and the electronic expansion valves located in each indoor unit. There are two alternative VRF models available in EnergyPlus to simulate the energy performance of VRF, but only "System Curve based Model" is introduced in the following.

The cooling power at each time step is calculated by the following equation:

$$Cooling\ Power\ (W) = \left(\frac{Q_{cooling,total,rated} CAPFT_{cooling}}{COP_{cooling,reference}}\right)\left(EIRFT_{cooling}\right)\left(EIRFPLR_{cooling}\right)(HPRTF) \quad (44)$$

where:

$Q_{cooling,total,rated}$ is the rated total cooling capacity of heat pump (W),

$COP_{cooling,reference}$ is the user specified coefficient of performance,

$CAPFT_{cooling}$ is the heat pump cooling capacity ratio modifier, and is the function of the load-weighted average wet-bulb temperature entering indoor units' coil ($T_{wb,avg}$) and the outdoor air temperature (T_C):

$CAPFT_{cooling} = a + b\left(T_{wb,avg}\right) + c\left(T_{wb,avg}\right)^2 + d(T_C) + e(T_C)^2 + f\left(T_{wb,avg}\right)(T_C)$ (45),

$EIRFT_{cooling}$ is the cooling energy input ratio modifier, and is the similar function of $T_{wb,avg}$ and T_C as the above function with different set of coefficients (a-f),

$EIRFPLR_{cooling}$ is the heat pump cooling energy input ratio modifier of part-load ratio, and is the function of the part-load ratio:

$EIRFPLR_{cooling} = a + b(PLR) + c(PLR)^2 + d(PLR)^3$ (46),

$HPRTF$ is the heat pump runtime fraction, and is the function of the cycling ratio:

$$HPRTF = \frac{Cycling\ ratio}{0.85 + 0.15(cycling\ ratio)} \quad (47)$$

$$cycling\ ratio = \frac{PLR}{PLR_{min}} \quad (48)$$

where PLR is the part-load ratio for the simulation time step, and PLR_{min} is the minimum part-load ratio of the VRF product.

The heating power at each time step is calculated by the following equation:

$$Heating\ Power\ (W) = \left(\frac{Q_{heating,total,rated} CAPFT_{heating}}{COP_{heating,reference}}\right)\left(EIRFT_{heating}\right)\left(EIRFPLR_{heating}\right)(HPRTF)\left(EIR_{defrost}\right) \quad (49)$$

where:

$Q_{heating,total,rated}$ is the rated total heating capacity of heat pump (W),

$COP_{heating,reference}$ is the user specified coefficient of performance,

$CAPFT_{heating}$ is the heat pump heating capacity ratio modifier, and is the function of the load-weighted average dry-bulb temperature entering indoor units' coil ($T_{db,avg}$) and the outdoor air temperature (T_C):

$$CAPFT_{heating} = a + b(T_{db,avg}) + c(T_{db,avg})^2 + d(T_C) + e(T_C)^2 + f(T_{db,avg})(T_C) \quad (50),$$

$EIRFT_{heating}$ is the heating energy input ratio modifier, and is the similar function of $T_{db,avg}$ and T_C as the above function with different set of coefficients (a-f),

$EIRFPLR_{heating}$ is the heat pump heating energy input ratio modifier of part-load ratio, and is the function of the part-load ratio:

$$EIRFPLR_{heating} = a + b(PLR) + c(PLR)^2 + d(PLR)^3 \quad (51),$$

$HPRTF$ is the heat pump runtime fraction, and is the function of the cycling ratio:

$$HPRTF = \frac{Cycling\ ratio}{0.85 + 0.15(cycling\ ratio)} \quad (52)$$

$$cycling\ ratio = \frac{PLR}{PLR_{min}} \quad (53)$$

where PLR is the part-load ratio for the simulation time step, and PLR_{min} is the minimum part-load ratio of the VRF product for heating.

$EIR_{defrost}$ is the adjustment factor for input power due to frost formation on the outdoor coil, and is the function of the difference between the outdoor air humidity ratio and the saturated air humidity ratio at the estimated outdoor coil temperature ($\Delta\omega_{coil,out}$):

$$EIR_{defrost} = 0.9 - 36.45(\Delta\omega_{coil,out}) \quad (54),$$

$$\Delta\omega_{coil,out} = MAX[10^{-6},\ \omega_{outdoor} - \omega_{saturated}(T_{coil,out},\ P_{outdoor})] \quad (55),$$

$$T_{coil,out} = 0.82T_{db,o} - 8.589 \quad (56)$$

where $\omega_{outdoor}$ is the outdoor humidity ratio, $\omega_{saturated}(T_{coil,out},\ P_{outdoor})$ is the saturated humidity ratio at outdoor coil surface temperature ($T_{coil,out}$) and outdoor barometric pressure ($P_{outdoor}$), and $T_{db,o}$ is the outdoor dry-bulb temperature.

Hot Water Boilers

Fuel consumption ($Fuel\ Used$) is calculated by the following equations:

$$Fuel\ Used = \frac{Boiler\ Load}{(Nominal\ Thermal\ Efficiency)(Boiler\ Efficiency\ Curve\ Output)} \quad (57)$$

$$Boiler\ Efficiency\ Curve\ Output = A_0 + A_1 \cdot PLR \quad (58)$$

where $Boiler\ Load$ is thermal load for the simulation time step, $Nominal\ Thermal\ Efficiency$ is the rated thermal efficiency using the higher heating value (HHV), and $Boiler\ Efficiency\ Curve\ Output$ is thermal efficiency as a function of part-load ratio (PLR) or both part-load ratio and boiler operating temperature. The above equation for $Boiler\ Efficiency\ Curve\ Output$ is the linear curve with only 1 dependent variable, but the quadratic and cubic curves can be assumed in EnergyPlus.

5.7.7.3 Calculation of Energy Use by Pump Systems

A typical primary-secondary water loop system in EnergyPlus is shown in Figure 11. It is assumed that pumps are placed on both demand side (secondary loop) and supply side (primary loop), that the pumps can have different schedules and each loop can be shut off when the other loop is still running.

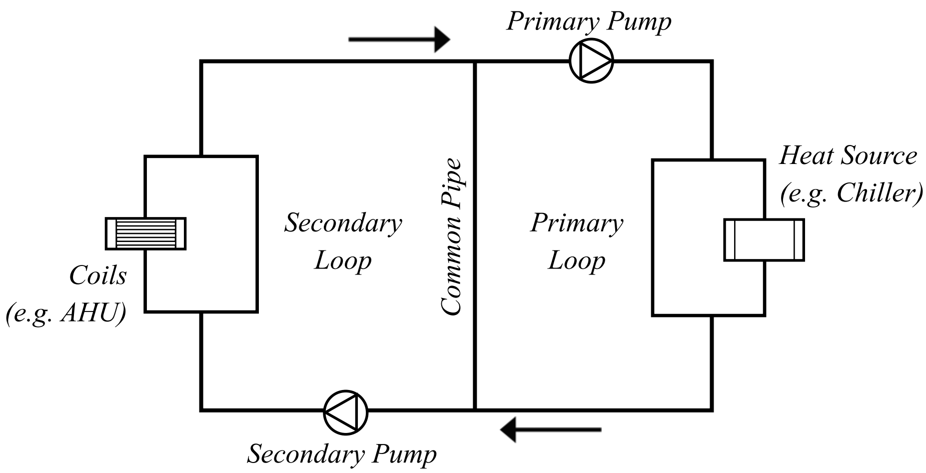


Figure 11 Pipe System Layout Schematic

For pumps, there are the following three different decision variables;

- constant or variable speed,
- the pump operation is continuous or intermittent, and
- whether or not there is request for overall loop flow.

After the overall loop flow request has been determined depending on requests of water by coils, if the pump is constant speed and operates intermittently, the pump will run at its capacity when a load is sensed and will shut off when there is no load on the secondary loop.

A variable speed pump is defined with maximum and minimum flow rates that are the physical limits of the device. When there is a load, the pump will operate and select a flow somewhere between the maximum and minimum limits to meet the flow request for the overall loop. Table X10 shows the input parameters for pumps. When a variable speed pump is used, the power consumption by the pump is calculated by multiplying the design power consumption and the fraction of full load power, as a function of the part load ratio, as shown in Table 36.

Table 36 Input Parameters for Pumps or Headered Pumps

Name of parameters	Unit	Note
Design maximum flow rate	m^3/s	-
Design pump head	Pa	-
Design power consumption	W	When using the auto size option, the design power consumption is calculated by using scaling factors (a) watt per unit design flow rate ($W/(m^3/s)$) or (b) watt per unit design flow rate per design pump head divided by motor efficiency. The default values are given for both (a) and (b).
Motor efficiency	-	-
Coefficient C1-C4	-	$Fraction\ of\ full\ load\ power = C_1 + C_2 PLR + C_3 PLR^2 + C_4 PLR^3$ where PLR is the part load ratio (current volume flow rate/design flow rate)
Design minimum flow rate	m^3/s	-
Control type		Continuous or intermittent
Flow rate schedule name		-
Variable Frequency Drive (VFD) control type		Pressure set point control or manual control. If the pressure set point control is selected, the schedule of the pressure range and allowable pump speed is required as input data.

5.7.7.4 Calculation of Energy Use by Fan Systems

The fan energy usage is often a large fraction of HVAC energy use and a significant portion of the building energy consumption. In the HVAC systems, fans are used for zone forced air units, which locally condition zones, such as fan coil units and package terminal air conditioners (Figure 12). Even though fans in such units and air conditioners consume energy and there are methods to control their operation to reduce fan energy use (see Section "19.6 Zone Equipment and Zone Forced Air Units" of Engineering Reference, 2019), the pressure loss to be overcome by the fans is not so large as the air system compound components groups, which service multiple zones by using duct networks. One example of the air system compound components groups, which are described in Section 16.5 of the Engineering Reference, is the unitary systems shown in Figure 12. Fans are used also for local ventilation such as in kitchens, lavatories, parking garages and electrical rooms, but fan energy controls for those fans are not deal with here.

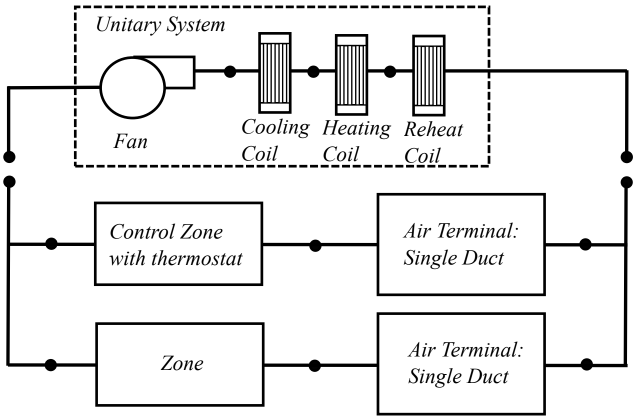


Figure 12 Schematic of the EnergyPlus Unitary System

In EnergyPlus, an object called “Fan:SystemModel” provides a simple polynomial-based curve-fit model to describe the relation between the volume flow rate and the fan electric power, with no explicit modeling of fan pressure rise. Consequently, duct-static-pressure reset strategies can only be modeled using curves that have been specially developed to approximate static pressure reset. There is another object for estimating fan energy use, that is called “Fan:ComponentModel” for CAV and VAV central air-handling systems. It provides a simple physics-based model for flow-dependent fan pressure rise and detailed models for fan, belt, motor and variable-frequency-driven efficiencies, and total energy use.

<u>Fan:SystemModel</u>

The user describes the fan by entering values listed in Table 37. For variable speed fan model, current fan electric power consumption is obtained by multiplying the design electric power consumption and a part load factor (f_{pl}) as a function of the flow fraction or part-load ratio. Figure 11 is an example of the function, which shall be assumed when compliance is checked by using the compliance approach (b) and (c) of ASHRAE Standard 90.1.

<u>Fan:ComponentModel</u>

This is a more detailed fan model that can be defined in the air loop for central constant-air-volume (CAV) and variable-air-volume (VAV) systems. It includes inputs parameters that describe the air-distribution system as well as the fan, its drive belt (if used), its motor, and its variable-frequency-drive (VFD) (if used). The variable-frequency-drive is a power electronic device that regulates the speed of an alternating current (AC) motor by adjusting the frequency and the voltage of the electrical power supplied to the motor. The above-mentioned Fan:SystemModel gives a direct relationship between the flow fraction or part-load ratio and the part-load factor for the electric power consumption, but it does not use information on efficiencies of fan, drive belt, motor nor VFD. In order to evaluate the influence of the efficiencies of such components on fan energy use, it is necessary to know the fan pressure rise so that fan shaft input power can be calculated. The following equation is proposed for Fan:ComponentModel to estimate the fan pressure rise ΔP_{fan}. To determine the coefficients $A_{fpr}, B_{fpr}, C_{fpr}, D_{fpr}$, it is necessary to use duct design calculation tools or to make measurements at different combinations of fan flows, outside air flow rates, damper positions and duct static pressures, and then to use non-linear system identification techniques to fit the data.

$$\Delta P_{fan,tot} = A_{fpr}Q_{fan}^2 + B_{fpr}Q_{fan} + C_{fpr}Q_{fan}\sqrt{P_{sm} - P_o} + D_{fpr}(P_{sm} - P_o) \tag{59}$$

$$\Delta P_{fan} = \Delta P_{fan,tot} - \frac{\rho}{2}\left(\frac{Q_{fan}}{A_{fan,out}}\right)^2 \tag{60}$$

where $\Delta P_{fan,tot}$ is the fan total pressure rise (Pa), ΔP_{fan} is the fan pressure rise (Pa), Q_{fan} is the fan flow rate (m^3/s), P_{sm} and P_o are the duct static pressure set point (Pa) and the static pressure of the space surrounding the duct (Pa), respectively, and A_{fan} is the fan outlet area (m^2).

Table 37 Input Parameters for Fans (Fan:SystemModel) Especially for Fan Energy Use Calculation

Name of parameters	Unit	Note
Schedule name for fan operation	-	-
Design maximum air flow rate	m^3/s	-
Speed control method	-	Continuous or Discrete
Electric power minimum flow rate fraction	-	When "Continuous" is selected, this parameter is a fraction of the design maximum air flow rate (0-1).
Design pressure rise	Pa	Altitude-adjusted standard density of dry air at 20°C
Design electric power consumption (Q_{design})	W	When "auto size" is input here, one the following three coefficients can be used to estimate the power consumption.
Electric power per unit flow rate	$W/(m^3/s)$	This is to be multiplied by the design maximum air flow rate.
Electric power per unit flow rate per unit pressure	$W/(m^3/s)/Pa$	This is to be multiplied by the design maximum air flow rate and the design pressure rise. 1.66667 is default value.
Fan total efficiency	-	The product of the design maximum air flow rate and the design pressure rise is divided by this parameter. 0.7 is default value.
Electric power function of flow fraction curve name		The independent "f_{flow}" variable is a normalized flow fraction defined as the current flow rate divided by the design maximum air flow rate. The curve name is referred to find coefficients c_1-c_5. In the following equation, f_{pl} is part load factor. $Current\ fan\ power\ (W) = Q_{design} \cdot f_{pl} = Q_{design} \cdot (c_1 + c_2 \cdot f_{flow} + c_3 \cdot {f_{flow}}^2 + c_4 \cdot {f_{flow}}^3 + c_5 \cdot {f_{flow}}^4)$
Number of speeds	-	When speed control method is "Discrete", this value is used.
Flow fraction of each discrete speed	-	Flow fraction of the design maximum air flow rate for each speed
Electric power fraction for each discrete speed	-	Electric power consumption fraction of the design electric power consumption for each speed

5.7.7.5 Simulation of Air Economizer

The air economizer is defined in ASHRAE Standard 90.1 as a duct and damper arrangement and automatic control system that together allow a cooling system to supply outdoor air to reduce or eliminate the need for mechanical cooling during mild or cold weather. The ability to simulate the air economizer is required for the compliance approach (c) in ASHRAE Standard 90.1, as shown in Table 7.

In the calculation for the baseline building and HVAC system with cooling capability, integrated air economizer shall be assumed, and when fans of the HAVC systems are not less than 2400 L/s and their outdoor air supply rates are not less than 70% of the total air flow rates, energy recovery system shall be assumed. In that case, the integrated control, by which the energy recovery system is bypassed, is simulated. The operation of the air economizer can be judged by single-point or multi-point controllers. Outdoor dry-bulb temperature, dew point temperature and enthalpy can be used for the economizer limit control.

5.7.7.6 Determination of Required HAVC Equipment Capacities

Both for the compliance approaches (b) and (c), simulation programs have to be capable of performing design load calculations to determine required HVAC equipment capacities and air and water flow rates in accordance with generally accepted engineering standards and handbooks for both proposed design and baseline or budget building design.

HVAC equipment sizing begins with the calculation of space heating and cooling loads, which the capability of terminal equipment (e.g., fan coil units) for each zone has to exceed with enough probability.

According to Appendix G of ASHRAE Standard 90.1, where a complete HVAC system exists for the proposed building, the model in the simulation shall reflect the actual system type using actual component capacities. On the other hand, component capacities for the baseline building shall be based on sizing runs. The ratio between the capacities used in the annual simulations and the capacities determined by the sizing runs shall be 1.15 for cooling and 1.25 for heating. Plant capacities shall be based on coincident loads (i.e., simultaneous loads, which may be less than the total design loads of equipment under consideration).

It is also required by ASHRAE Standard 90.1 that weather conditions used in sizing runs to determine baseline equipment capacities shall be based on design days developed using heating design temperature, cooling design temperature, and cooling design wet-bulb temperature. In addition, for cooling sizing, schedules for internal loads, lighting, gas and electricity using equipment, shall be equal to the highest hourly value used in the annual simulation runs and applied to the entire design day. For heating sizing, schedules for internal loads, including those used for occupants, lighting, gas and electricity using equipment, shall be equal to the lowest hourly value used in the annual simulation runs and applied to the entire design day.

6. Key International Standards for HVAC Energy Calculation

6.1 Set of international standards on the overall energy performance of buildings (EPB standards)

6.1.1 General introduction

The set of standards on the energy performance of buildings (set of EPB standards) have been prepared under a mandate given to CEN by the European Commission (Mandate M/480, 2010), to support the EPBD. The EPBD, the European Directive on the energy performance of buildings aims to promote the improvement of the energy performance of buildings within the European Union, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness.

The mandate M/480 was issued as the recast of the EPBD, which raised the need to revise and reformulate already existing standards, and to add standards so that they become on the one hand unambiguous and compatible, and on the other hand a clear and explicit overview of the choices, boundary conditions and input data that need to be defined at national or regional level.

Such national or regional choices remain necessary, due to differences in climate, culture & building tradition, policy and legal frameworks[14]. For instance, there are choices on specific detailed or more simplified methods (e.g. hourly or monthly calculation), in references to other standards (enabling a step-by-step implementation of the set), typology (e.g. building and space categories), boundary conditions (e.g. climatic data, conditions of use per building or space category), and input data (e.g. policy factors, default values, etc.).

The Mandate M/480 was a follow up on the Mandate M/343 which had led to a first generation of EPB standards (2004-2008), in support of the first version of the EPBD (2003). Already then, many of these standards were developed (and partly already available) as combined CEN ISO standards, in particular on the building energy needs, climatic data and building components (ISO/TC 163 and CEN/TC 89).

Under the new mandate, M/480, the development of the new set of EPB standards was even more dedicated to become relevant at global (ISO) level. For instance, the main EPB standard, the EPB overarching standard EN ISO 52000-1, and the subset of EPB standards on building energy needs and building elements are available as EN ISO standards at global level, in a cooperation between CEN (Europe) and ISO (worldwide).

In general, the EPB standards were developed in five CEN Technical Committees (Europe), in two ISO Technical Committees (worldwide), each covering a specific expertise. A core expert group of all EPB standard developers secured and promoted overall consistency of the approach and of the technical details. After the publication of the set of EPB standards in 2017, the EPB Center was initiated to provide technical support in the implementation and planning of further development.

The following overview (Figure 10) shows the main standards of the EPB set[15]:

[14] https://epb.center/epb-standards/flexibility-national-choice/

[15] List of all EPB standards: https://epb.center/documents

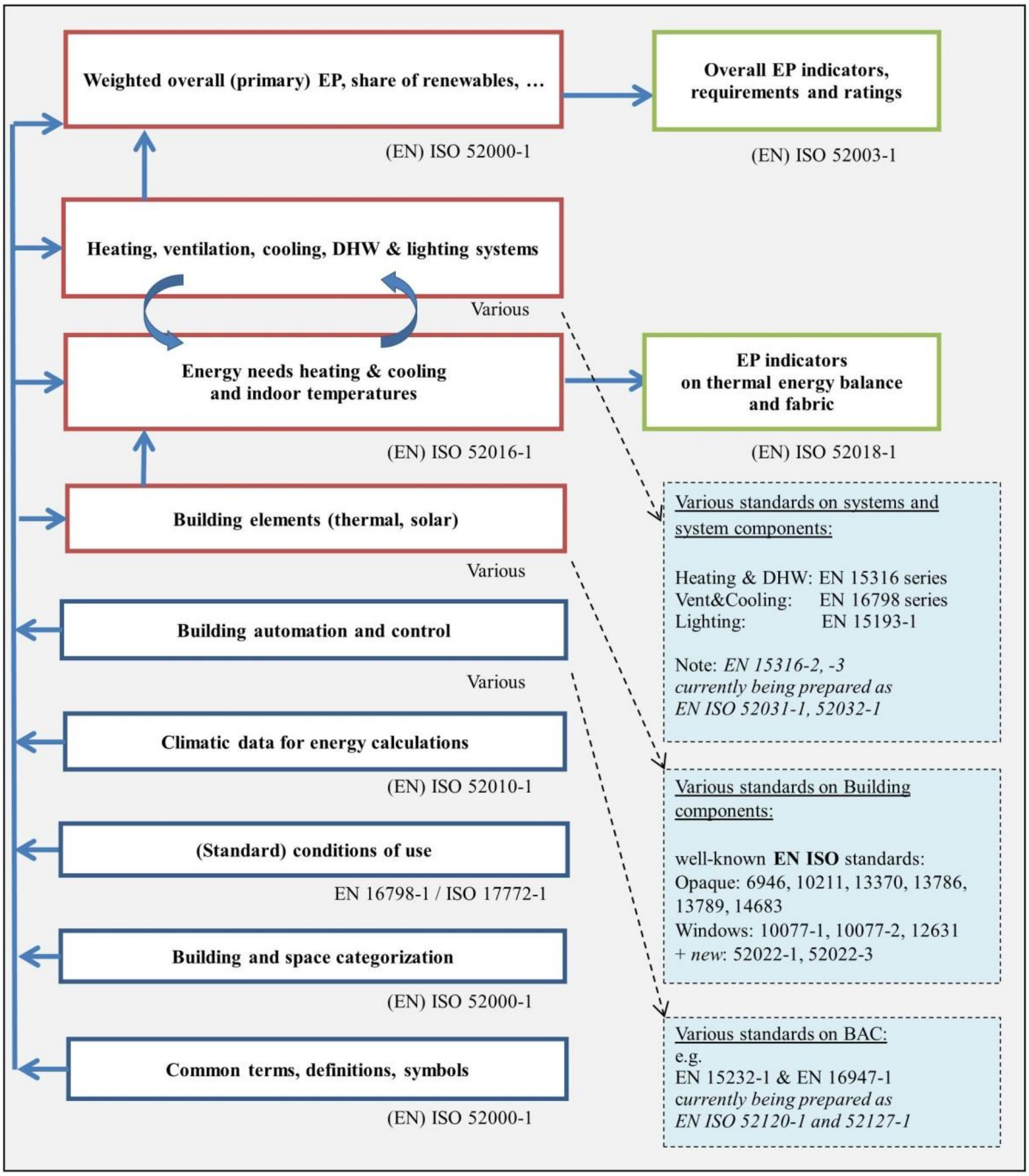


Figure 13 Schematic overview of the set of EPB standards

As shown in the diagram, the overarching EPB standard covers several overarching elements: common terms, definitions and symbols, building and space categorization (typology; assessment boundaries) and aggregation to overall primary energy and CO_2 emission, including related items such as appreciation of surplus of on site produced electricity, share of renewables and such. The specific choices and values for these kind of factors can be chosen at national level. A new standard is in preparation, EN 17423 (future: EN ISO 52000-3), to attain transparency on the determination (basis) of such factors, which can have a strong impact on the assessed EPB and, consequently, on the comparison between countries.

As also shown in the diagram, an increasing number of EPB standards that are until now only available in

Europe (CEN) are now being developed as combined EN ISO standards[16]. This concerns in particular the system related EPB standards. In the latest (2018) version of the EPBD the EU Member States are requested to pay extra attention to the following five EPB standards (all shown in the diagram):

EN ISO 52000-1: 2017 “Energy performance of buildings - Overarching EPB assessment - Part 1: General framework and procedures”
EN ISO 52003-1: 2017 “Energy performance of buildings - Indicators, requirements, ratings and certificates - Part 1: General aspects and application to the overall energy performance”
EN ISO 52010-1: 2017 “Energy performance of buildings - External climatic conditions - Part 1: Conversion of climatic data for energy calculations”
EN ISO 52016-1: 2017 “Energy performance of buildings - Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads - Part 1: Calculation procedures”
EN ISO 52018-1: 2017 “Energy performance of buildings - Indicators for partial EPB requirements related to thermal energy balance and fabric features - Part 1: Overview of options”

Each of these standards represents a core step in the overall EPB assessment. Because the technical building systems cover various services and a wide range of possible technologies, products and/or components it is more difficult to catch these in one or a few standards. This subset of EPB standards is described further below.

It should be note that each of the EPB standards is accompanied by a Technical Report that provides explanation and justification of the methodology plus worked out examples. These examples are based on spreadsheets that has been prepared during the development of each EPB standard, for validation and demonstration[17].

According to EN ISO 52000-1 the building (or part of the building) can be divided into thermal zones and service areas. Where possible, the building is considered as a single thermal zone. However, the energy performance calculation may require that it is divided into thermal zones depending on:
— the differentiation in conditions of use over the spaces in the building;
— the complexity of the building (building physics, building units, etc.);
— the complexity of the technical building systems (control, losses).
Then the thermal balance calculation is performed separately for each thermal zone and not directly for the whole assessed object.
Also, where possible, the building is considered as a single service area for each service (heating, cooling, domestic hot water, ventilation, lighting). However, for one or more services, the energy performance calculation may require that the assessed object is divided into different service areas, depending on the complexity of the technical building systems.
The division of the building into service areas is in principle done separately for each service. In this way, it is avoided that if a more refined division into service areas is needed for one service, this would also be needed for all other services.

[16] More info: https://epb.center/epb-standards/iso-and-cen-road-ahead
[17] More information at https://epb.center/epb-standards/technical-reports/
https://epb.center/documents/

Example: A service area for lighting and a service area for domestic hot water needs can be specified and calculated independently from each other.

The influence of technical building systems on the thermal balance, in the form of dissipated heat or cold, is taken into account per thermal zone.

Where the service area for a service does not coincide with a thermal zone, simple subdivision and aggregation rules are introduced. The details of the rules can be tuned to the national context, e.g. depending on the level of subdivision into different space categories (each requiring different conditions of use).

The procedure to assess the thermal zones is covered in (EN) ISO 52016-1, involving 10 successive steps, are highly inspired by DIN V 18599-1. The main difference is that the rules in ISO 52016-1 are made more flexible and more generic. In addition: the details can be tuned to the national context (e.g. depending on the required level of accuracy, reproducibility, maximum effort to acquire input data).

6.1.2 EN ISO 52016-1, monthly and hourly calculation method

One of the key choices in the calculation methodology is the choice between a monthly and an hourly calculation method. EN ISO 52016-1:2017 is the successor of EN ISO 13790:2008.

Of all EPB standards, the choice between hourly or monthly calculation procedures is most prominently visible in the calculation of the energy needs for heating and cooling and indoor temperatures: ISO 52016-1 (International Organization for Standardization, 2017). This standard superseded the well-known ISO 13790 (International Organization for Standardization, 2008). EN ISO 13790 has been adopted or partly copied in many building energy calculation methodologies all over the world, as also shown elsewhere in this report (see e.g. the monthly utilization factor approach).

Like its predecessor, ISO 52016-1 contains, side by side, both a monthly and an hourly calculation method. The monthly calculation method in ISO 52016-1:2017 has not been fundamentally changed compared to ISO 13790:2008. It contains correction or correlation factors to account, in a kind of statistical way, for the dynamic effects.

However, for low energy buildings and buildings with dynamically (inter-)acting technologies, the monthly method is no longer the simple transparent method that it used to be. Due to the necessity to introduce an increasing number of correction or correlation factors, the original transparency and robustness of the monthly method has been lost. The more of the above mentioned dynamic technologies and processes are included in the monthly calculation method, the less transparent the monthly calculation method becomes, and the more an hourly method becomes the transparent alternative.

An hourly calculation method does not need the series of correction factors that the monthly method requires. It can directly calculate the effect of dynamic interactions. But the challenge for an hourly method is to avoid the need for too many input data from the user. More input data would introduce more uncertainties that could easily lead to a loss of overall accuracy, or lead to significantly higher assessment compared to its predecessor (ISO 13790:2008), in two ways:

In contrast to ISO 13790, ISO 52016-1 contains a full dynamic method. In this way ISO 52016-1 resembles building simulation tools more closely. On the other hand, the details of this hourly method in ISO 52016-1 have been tailored to the goal: they are spelled out unambiguously and transparently and, equally important: the hourly calculation method does not require extra input from the user compared to the monthly calculation method. This lowers the threshold to make the step from monthly to hourly calculations.

The hourly and the monthly method in ISO 52016-1 are closely linked because they have been developed side by side and they use the same input data and assumptions. Consequently, the hourly method is also very well suited for the derivation or validation of the correction and correlation factors of the monthly method. For instance, by carrying out a large number of hourly calculation runs for a specific range of building categories, with a variety of building types and designs. This is illustrated by the flow chart (Figure 14).

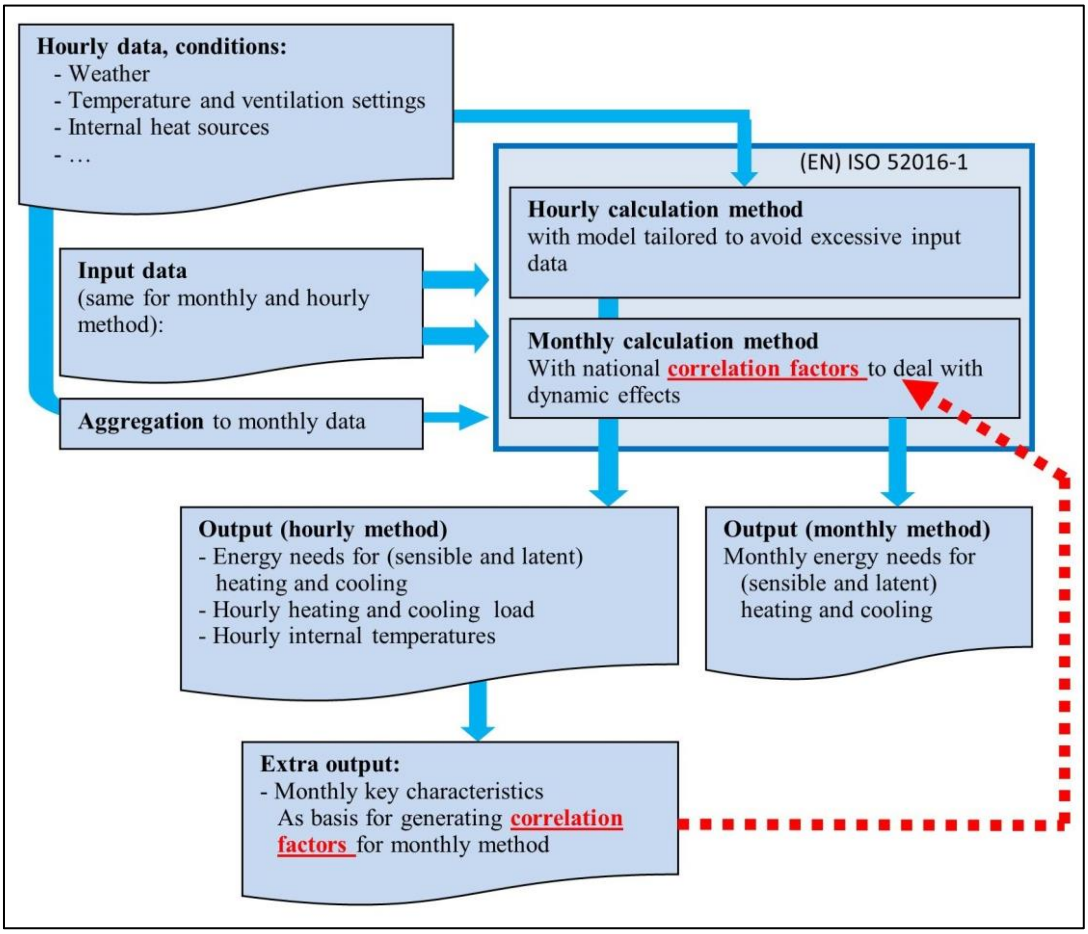


Figure 14 ISO 52016-1: links between the hourly and the monthly method provided in this standard

Normally, another dynamic simulation tool is needed for such purpose; with the consequence that differences in assumed conditions and differences in model approaches lead to significant noise in the derivation/validation of the correction or correlation factors. By using both the hourly and the monthly method from ISO 52016-1 this noise is eliminated.

6.1.3 EPB standards on HVAC systems

Other standards necessary to deal with technical building systems including HVAC systems still exist as EN standards, even though some have been newly developed. Among them, some of EN 16789 series are especially relevant to the energy calculation of HVAC systems. These can be listed as;

EN 16798-3: 2017 “Energy performance of buildings. Ventilation for buildings. For non-residential buildings. Performance requirement for ventilation and room-conditioning systems”

EN 16798-5-1: 2017 “Energy performance of buildings. Ventilation for buildings. Calculation methods for energy requirements of ventilation and air conditioning systems. Method 1: Distribution and generation”

EN 16798-5-2: 2017 “Energy performance of buildings. Ventilation for buildings. Calculation methods for energy requirements of ventilation and air conditioning systems. Method 2: Distribution and generation”

EN 16798-7: 2017 “Energy performance of buildings. Ventilation for buildings. Calculation methods for the determination of air flow rates in buildings including infiltration

EN 16798-9: 2017 “Energy performance of buildings. Ventilation for buildings. Calculation methods for energy requirements of cooling systems. General”

EN 16798-11: 2017 “Energy performance of buildings. Calculation of the design cooling load”

EN 16798-13: 2017 “Energy performance of buildings. Calculation of cooling systems. Generation”

EN 16798-15: 2017 “Energy performance of buildings. Calculation of cooling systems. Storage. General”

Table 38 Summarizes scopes of EN 16798 series.

Table 38 Scope of EN 16798 Series

EN Number	Scope
EN 16798-3	Definitions of various parameters for ventilation, air conditioning and room conditioning systems for non-residential buildings
EN 16798-5-1	Energy performance calculation for air handling unit and duct system of mechanical ventilation and air conditioning systems, by using hourly time step
EN 16798-5-2	Energy performance calculation for air handling unit and duct system of mechanical ventilation and air conditioning systems, by using monthly or seasonal time step
EN 16798-7	The methods to calculate the ventilation air flow rates including those not only by mechanical ventilation systems but also by window openings
EN 16798-9	Energy performance calculation of whole cooling systems covering cooling energy need of thermal zones with emission losses, losses due to multiple distribution systems (air handling units and ducts) and auxiliary energy use.
EN 16798-11	Calculation method of sensible design cooling load, condition of supply air and design heating load
EN 16798-13	Calculation method of water temperatures (chilled water inlet and outlet, cooling water inlet), thermal energy extraction and energy use of cold generator (chiller)
EN 16798-15	Energy performance calculation of storage systems

Among the EN 16798 series, the standard closest to the performance of heat and cold generators is EN 16798-13, in which two methods are mainly prescribed for calculating electrical energy (in case of compression type systems) and heat (in case of absorption type systems) consumption. Method A uses an hourly time step and requires EN 14825 product data. Method B uses hourly or monthly time step and can be applied to chillers, multi-split and Variable Refrigerant Flow systems.

The relationship among EN 16798 standards and relevant other CEN standards is shown in Figure 15, which is followed by descriptions on key standards.

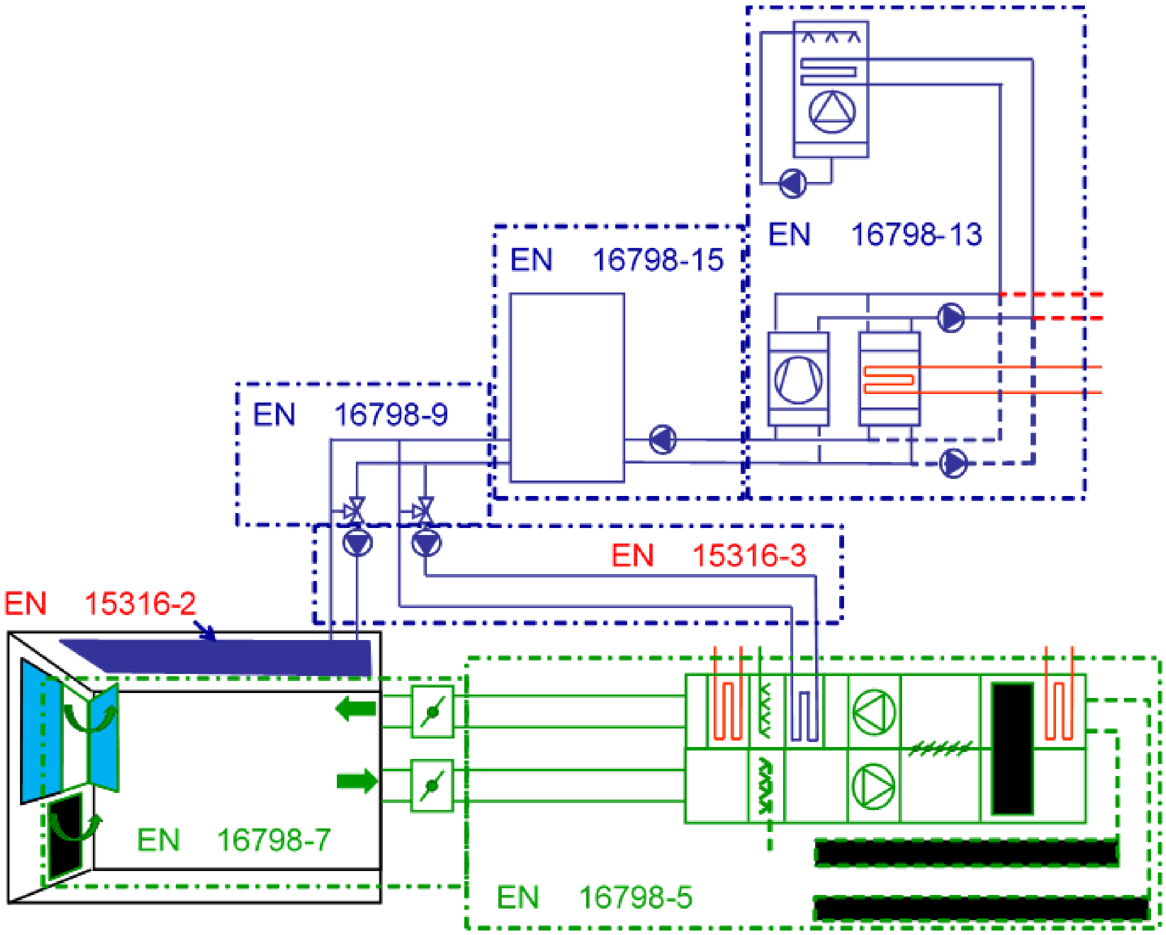


Figure 15 Overview of the use of the EN 16798 series of standards on HVAC systems (emission, distribution and generation)

EN 16798-7 covers mechanical and natural ventilation systems (mechanical exhaust, mechanical supply or balanced system), passive duct ventilation systems for residential and low-rise non-residential buildings, combustion appliances, window openings (manual or automatic operation) and kitchens where cooking is for immediate use (including restaurants). For airflow rate calculations, two methods are prescribed as follows;

- method 1 based on detailed building characteristics
- method 2 based on statistical approach (a simplified approach)

EN 16798-5-1 is one of the two standards for energy performance calculation for air handling unit and duct system of mechanical ventilation and air conditioning systems, and it is intended to cover a number of modules in the areas of distribution, i.e. the duct system, and the air handling unit (AHU), including humidification and dehumidification. This standard describes a detailed method for calculating energy use by ventilation and air conditioning systems, and uses an hourly calculation step. It is a comprehensive calculation of all aspects of air conditioning systems. The distribution part includes the calculation of duct heat losses and duct leakage, both linked to the zones crossed and/or served by the system.

The air handling unit part includes the ordinary air treatment steps for heating, cooling dehumidification and humidification. This standard has many options to be chosen, many of them being control options with a link to the building automation (see the CEN/TC 247 standards), especially the revised EN 15232-1:2017 "Energy Performance of Buildings. Impact of Building Automation, Controls and Building Management. Modules M10-4,5,6,7,8,9,10", which has been updated to reflect the following options:

- Different air flow control types: Depending on the calculation of the required air flow rates on zone level, which is covered in EN 16798-7, the flow rate control in the AHU can be constant, multi stage or variable.
- Supply air temperature and humidity control types: constant, outdoor air compensated or load compensated.

Only one of the two options (air flow or temperature) can be load dependent in the calculation method in this standard.

Fans can be controlled differently to react on the flow control. A direct link is only possible for single zone systems (e.g. serving cinema theaters or auditoria). For multi zone systems, the flow control is usually done on zone level (e.g. by VAV boxes), and the central fan is controlled e.g. pressure dependent. Based on an input from CEN/TC 247, there are several options considering the type of pressure measurement. Experience showed that this has a significant impact on the fan energy use. The fan energy calculation is linked to inputs from product standards of fans.

This standard also covers different types of heat recovery, i.e. plate type, rotary type with different types of coatings (hygroscopic, non-hygroscopic, absorptive) including humidity recovery, and pumped circuit type. For the calculation there is a connection to product standards (EN 308, EN 13053), and it includes the aspects of control, different ways of frost protection and auxiliary energy consumption. As the calculation of rotary heat exchangers with the humidity recovery and the auxiliary energy calculation involves a lot of input data, and a part of the calculation was transferred to an informative annex, leaving a generic function to be defined nationally in the normative part. The annex is referred to for the "CEN option" in Annex B.

Further options are recirculation control and humidifier types (adiabatic or steam, involving different energy carriers) with different controls.

The method covers also a couple of special innovative solutions:

- Ground preheating/-cooling, which is described in an informative annex
- Adiabatic cooling by humidification of extract air and heat recovery.

The accompanying CEN/TR 16798-6 is a common document for this standard EN 16798-5-1 and for EN 16798-5-2. It gives explanations for the background of different options and choices. It shows also example ways of zoning.

A recently updated spreadsheet is fully functional and has a drop-down menu structure to choose all the options[18]. This spreadsheet can be downloaded from www.epb.center.

EN 16798-5-2 covers energy performance calculation of mechanical ventilation systems with integrated heating/cooling generation, including domestic hot water production, using a monthly or seasonal calculation interval or a bin method. It takes into account the air handling unit and distribution (duct system)

[18] The excel files are publicly available via www.epb.center

parts. It does not cover the emission part (calculation of the required airflow rates and/or supply air conditions), which is covered by EN 16798-7. It does not include humidification and dehumidification. This method is focussed on small, packaged ventilation systems, typically used in residential buildings, although the application is not restricted on the basis of building or space use type.

EN 16798-9 is the core of the cooling related calculation standards, the "general" part. This standard describes the interconnection of modules and includes a simplified method for zone-emitter based DX (direct expansion) systems, air-distribution based DX systems and water-based systems as well. For schematics, see CEN TR 16798-10:2017 “Energy performance of buildings - Ventilation for buildings - Part 10: Interpretation of the requirements in EN 16798-9 - Calculation methods for energy requirements of cooling systems (Module M4-1, M4-4, M4-9) - General”.

EN 16798-9 connects the calculation pieces of the other standards for emission, distribution, storage and generation to a complete system, considering the flow rate and temperature control of the distribution branches and the load dispatching in case of insufficient energy supplied by the generation system. It follows (as the other parts do) the principle, that a subsequent energy using module reports the required energy supply to the delivering module per calculation interval, and this in turn reports the energy really delivered, based on its operational conditions, back to the using module per calculation interval.

As shown in Figure 16, a schematic representation is given in the standard, illustrating the boundaries of the involved modules and the nomenclature used in the detailed calculation method of the standard. The (non-exhaustive) system shown in this scheme, with a generation, a storage and two distribution branches, each serving two thermal zones and one air handling unit, is exactly represented in the spreadsheet going along with the standard. In this spreadsheet, a full annual data set of hourly values is implemented to test the calculation. An hourly calculation interval is needed for this detailed calculation method.

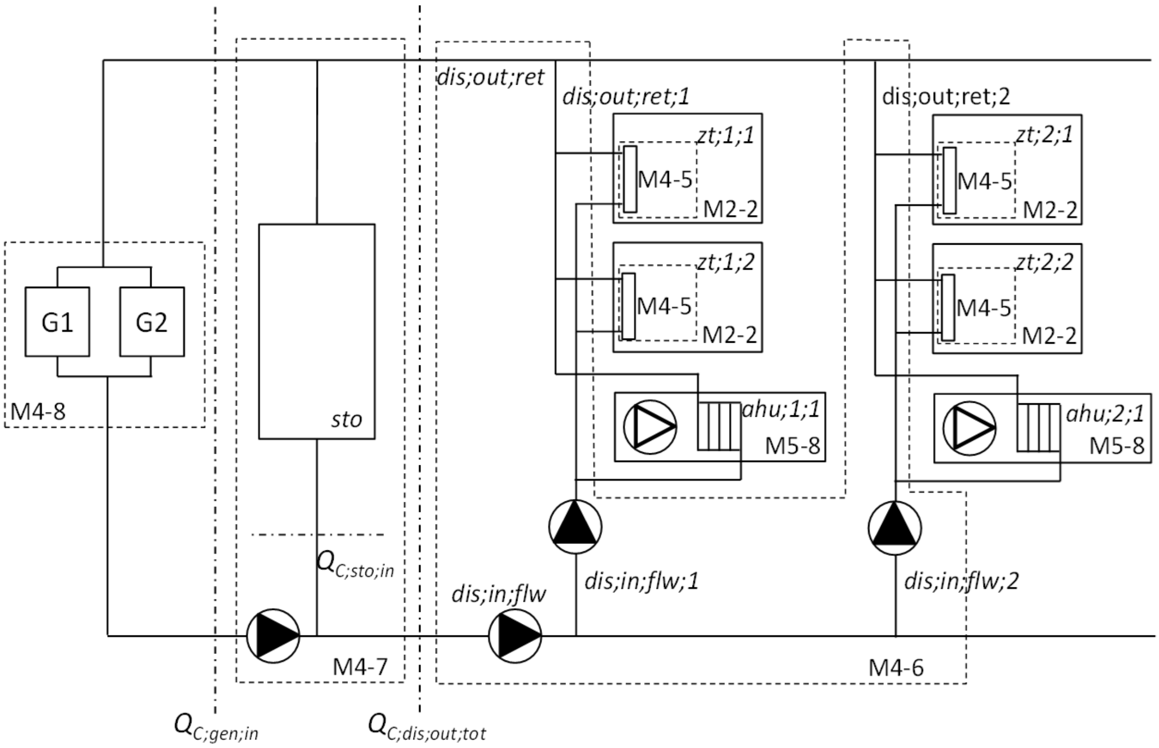


Figure 16 A typical HVAC system dealt with in EN 16798-9

This figure shows the most general case covered by the detailed calculation method. The simplified calculation method treats the distribution parts in a simplified way for water-based systems. For DX systems it is skipped completely.

For the water-based emission and distribution calculations (modules M4-5 and M4-6) it refers to the CEN TC 228 heating system standards (EN 15316-2 and 3). For the storage calculation it refers to EN 16798-15 and for the generation to EN 16798-13.

In the simplified calculation method, which can also be applied to a monthly calculation interval, the distribution is covered by simply applying factors to the heat extracted from the zones and AHU's. Also, a storage calculation is not applicable. This method also addresses DX (direct expansion) systems, in which case the calculation becomes generally simpler. The emission can be zone based or via air systems. Schematic representations are given in the accompanying CEN/TR 16798-10.

A separate spreadsheet was developed for this simplified calculation method (see www.epb.center).

The standard also covers module M4-4 with two partial performance indicator proposals for cooling systems.

In the accompanying technical report CEN/TR 16798-10, examples are given for the simplified and detailed calculation methods, where the spreadsheets are provided for. This includes also an example with a whole set of linked spreadsheets for the setup shown in figure 3 of the standard. According to the number of zones, AHUs and distribution branches, there are multiple instances of several of the spreadsheets. With this setup, the functionality of the whole set of calculations in the cooing area can be demonstrated.

An issue of importance repeatedly mentioned by stakeholders is ventilative cooling, i.e. cooling by enhanced natural and/or mechanically assisted ventilation. This cannot be covered by one standard, since it involves the thermal zone calculation as well as flow rate calculations and control issues. Therefore, a description of the necessary procedure, the modules involved and the information flow is given in the accompanying TR.

EN 16798-13 is the standard for the cooling generation calculation, which contains 2 Methods:

- Method A for an hourly calculation step;
- Method B for a monthly calculation step.

The technologies covered in both methods are 1) compression/absorption chillers, 2) place holder for "other" type of generator used for direct use of boreholes, ground or surface water, 3) multiple generators handling, 4) “Free cooling” control option, i.e. direct cooling via heat rejection device, 5) different heat rejection types, 6) air cooled condensers, 7) dry, wet and hybrid heat recovery devices, and 8) control options for the heat rejection (e.g. switch between dry and wet operation for hybrid heat rejectors).

In method A, there is a connection to product standards for compression chillers: A performance map is used, which is generated on the base of the measurement points from EN 14511 tests, which are used in EN 14825 for the calculation of the SEER. For additional flexibility, the method has been extended to include the case relying only on the nominal EER according to EN 14511, or, if even this is missing, a default nominal EER value. The approach for this case is a constant exegetics efficiency. This was needed because it is not mandatory for the suppliers to provide the EN 14825 based SEER and the related EER values before 2018, and therefore it cannot be expected to get these values in all cases.

An accompanying CEN TR 16798-14 and two separate spreadsheets for the two methods are available for this standard.

EN 16798-15 deals with the cooling storage, of which energy efficiency has an indirect impact as the consequence of such installation depends on the design and purpose:

- To reduce the power of the cooling generation as the peak demand for cooling is insured alone (energy shift) or in supplement of the cooling generation,
- To offer operation of the cooling unit with a higher load factor and consequently increase the energy efficiency of the cooling generation,
- To increase safety for a definite period to avoid oversizing of the cooling generation plant.

The standard allows to calculate the energy performance for these different modes and is now fully integrated with the modules for cooling generation and cooling distribution. Storage can be used with water/ice and other materials (Phase change materials) offering a various range of properties (latent energy capacity, temperatures for fusion and solidification). Calculation have been simplified and consider the transformation of the material as completed during the time step (for 1 hour to larger time-step).

As for other EPB standards, there is an Annex A and B. Annex B presents default values to characterise the performance of the storage unit and type of materials used for storage. Examples illustrate the case for water/ice and Phase Change Material.

6.2 Other International Standards relevant to HVAC energy Calculations

EN 14825: 2013 “Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling – Testing and rating at part load conditions and calculation of seasonal performance” is referred in EN 16798-13. This is also referred to by UNI/TS 11300-3. This EN 14825: 2013 is for factory made air conditioners, heat pumps and liquid chiller packages, of which test conditions are defined in EN 14511-2 “Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling Part 2: Test conditions”.

EN 14825: 2013 defines the calculation method for determination of reference seasonal energy efficiency SEER (for cooling) and reference seasonal coefficient of performance SCOP (for heating). For example, SEER can be determined by the following equations. The most critical parameter is $EER_{bin}\,(T_j)$ in the equation for $SEER_{on}$. The energy efficiency of cold and heat generators is heavily dependent on the capacity ratio of the machine (cold or heat generation at the condition divided by the maximum capacity of cold or heat generation) and on outdoor temperature. These dependencies are usually the most critical factor when evaluating the energy efficiency of all kinds of generators. As prescribed in chapter 4 of EN 14825: 2013, the tests of the unit at least 4 conditions of part load ratio ranging from 100% to about 20% must be carried out according to EN 14511-3. Based on the test results, for staged and variable capacity unit $EER_{bin}\,(T_j)$ is calculated by using the closest measured value or by linear interpolation, without considering the deterioration of efficiency due to intermittent cyclic on-off, if extrapolation is not necessary. For fixed capacity unit, the degradation coefficient (C_D), of which default value is 0.25, is used to calculate $EER_{bin}\,(T_j)$.

$$SEER = Q_C / Q_{CE} \tag{61}$$

$$Q_C = P_{designc} \times H_{CE} \tag{62}$$

$$Q_{CE} = \frac{Q_C}{SEER_{on}} + H_{TO} \times P_{TO} + H_{SB} \times P_{SB} + H_{CK} \times P_{CK} + H_{OFF} \times P_{OFF} \tag{63}$$

$$SEER_{on} = \frac{\sum_{j=1}^{n} h_j \times P_C(T_j)}{\sum_{j=1}^{n} h_j \left(\frac{P_C(T_j)}{EER_{bin}(T_j)}\right)} \tag{64}$$

where

Q_C : reference annual cooling demand (need) in kWh;

Q_{CE} : reference annual electricity consumption (energy use) in kWh;

$P_{designc}$: full load of the unit in kW;

H_{CE} : number of equivalent active mode hours for cooling;

H_{TO} , P_{TO} : number of hours and electricity consumption during thermostat off, respectively;

H_{SB} , P_{SB} : number of hours and electricity consumption during standby mode, respectively;

H_{CK} , P_{CK} : number of hours and electricity consumption during crankcase heater mode, respectively;

H_{OFF} , P_{OFF} : number of hours and electricity consumption during off mode, respectively;

T_j : bin temperature;

h_j : number of bin hours occurring at the corresponding temperature T_j ;

$P_C\,(T_j)$: cooling demand (need) of the building for the corresponding temperature T_j ;

$EER_{bin}\,(T_j)$: EER values (energy efficiency ratio; cooling capacity divided by power input) of the unit for the corresponding temperature T_j

In United States of America, the standards listed in Table 39 exist for calculating energy efficiencies of air-conditioning and heat pump equipment. In AHRI 210/240-2017, SEER (Seasonal Energy Efficiency Ratio) for unitary air-conditioners (air-cooled), SEER and HSPF (Heating Seasonal Performance Factor) for unitary air-source heat pumps are prescribed among minimum data requirements for published ratings. In AHRI 340/360-2019, IEER (Integrated Energy Efficiency Ratio) for unitary air-conditioning equipment and IEER and COP_H (heating coefficient of performance at 8.3 °C and -8.3 °C) for unitary heat pump equipment are prescribed among minimum data requirements for published ratings. In AHRI 1230-2014, SEER or IEER for VRF multi-split air-conditioners and SEER and HSPF for VRF multi-split heat pumps are prescribed among minimum data requirements for published ratings.
The IEER is weighted average of EERs at 100%, 75%, 50% and 25% capacity with condenser temperature of each capacity of products. It is mentioned in AHRI 340/360-2019 and AHRI 1230-2014 that the IEER is not intended to be a predictor of the annual energy consumption of a specific building in a given climate zone (chapter 6.5).
The SEER (in Btu/W·h) is the ratio of total building cooling load (in Btu) for eight Temperature Bins to total electric consumption (in W·h) for the eight Temperature Bins. The HSPF (in Btu/W·h) is the ratio of total building heating load (in Btu) for eighteen Temperature Bins to total electric consumption (in W·h) for the eighteen Temperature Bins adjusted by a demand-defrost enhancement factor.

Table 39 American standards for calculating seasonal energy efficiencies and other indices of air-conditioning and heat pump equipment (AHRI standards)

AHRI Standards' Number	Title and Scope
210/240-2017	Performance Rating of Unitary Air-conditioning & Air-source Heat Pump Equipment (scope: factory-made machines with capacities less than 65,000 Btu/h, namely 19kW)
340/360-2019	Performance Rating of Commercial and Industrial Unitary Air-conditioning and Heat Pump Equipment (scope: factory-made machines except for the target of 210/240-2017 and variable refrigerant flow air-conditioners and heat pumps as the target of 1230)
310/380-2017	Packaged Terminal Air-conditioners and Heat Pumps· CSA-C744-17
1230-2014	Performance Rating of Variable Refrigerant Flow (VRF) Multi-Split Air-Conditioning and Heat Pump Equipment (scope: split system that has one outdoor unit and two or more indoor units and/or blower coil indoor Units connected with a single refrigerant circuit)

In Japan, the standards listed in the following table are used for rating energy efficiencies of air-conditioning and heat pump equipment by prescribing Annual Performance Factor (APF). However, in the national building energy calculation method, APF is not referred to and rated energy efficiencies such as COP is used with certain assumptions for energy efficiency's dependency on outdoor air, cooling water and partial load condition as already introduced in Figure 7. It is because calculation results of heating and cooling needs for target buildings by the national energy calculation method are much more useful and appropriate for the evaluation of the target buildings than the heating and cooling needs assumed for calculating APF without taking specifications of the target buildings.

Table 40 Japanese standards for calculating seasonal energy efficiencies of air-conditioning and heat pump equipment (JIS standards)

JIS Standards' Number	Title and Scope
C 9612: 2013	Room Air Conditioner (scope: room air conditioner with cooling rated capacity not exceeding 10 kW or multi split room air conditioners with more than one indoor unit and with rated cooling capacity not exceeding 28 kW)
B 8616: 2015	Package Air Conditioners (scope: electrically driven air conditioners designed mainly for non-residential buildings with rated cooling capacity not exceeding 56 kW)
B 8627: 2015	Gas Engine Driven Heat Pump Air Conditioners (scope: gas engine driven air conditioners with rated cooling capacity not exceeding 85 kW)

7. Summary for Key Aspects of Existing National Calculation Methodologies and Relevant International Standards

7.1 Space unit and zoning rules for energy use calculation of space heating/cooling, ventilation and lighting

In DIN V 18599, its zoning rule is prescribed in Chapter 6 of DIN V 18599-1. The zone comprises the base area or area of a building whose rooms are characterised by uniform conditions of use and heating, cooling, ventilation, humidification, lighting and domestic hot water supply by the same type of conditioning and uniform zone criteria. The process of setting zones is divided into three steps;

1. Creation of areas of equal use
2. Division of the area if it contains zones with different requirements for thermal or lighting conditioning, or if it contains zones serviced by different ventilation and air conditioning systems. Division of the area if it contains different daylight conditions or different characteristics of façade.
3. Small zones accounting up to 5% of the total area of the building may be added to other zones with similar technical conditioning but different uses. Very small zone accounting up to 1% of the total floor area of the building may be added to another zone.

In BECS, as the most fundamental input data, a list of rooms in the evaluated building is compiled. Each room in the list has to have its own unique name, by which the room can be identified in submitted design drawings and in other input data sheets. The list also contains the room category, building category to which the room category belongs, floor area, floor height, ceiling height and applicable services (space heating and cooling, ventilation for outdoor intake, lighting and domestic hot water). If a space is divided by the partition wall, it shall be divided into rooms without inside partition walls. If a space is serviced by different types of independently controlled indoor terminals of HVAC systems or by different outdoor units for multi-split VRF systems, the space shall be divided into rooms, which will be the base for defining air conditioning zones. As for lighting, if a space is serviced by different lighting systems, it shall be divided into rooms.

In SBEM, its zoning rule is prescribed in National Calculation Methodology modelling guide, as already mentioned in 5.6.2. Thermal zone and lighting zone need to be determined. A thermal zone can contain multiple lighting zones, but a lighting zone cannot extend across the boundary of thermal zones.

7.2 Types of HVAC Systems and Heat Sources to Be Focused in National Calculation Methodologies

DIN V 18599-7 calculates the energy consumption for the air handling unit in cooling mode. All systems for zone heating are evaluated using DIN V 18599-5, while all systems for zone cooling are evaluated using DIN V 18599-7. In Table 41, configurations of HVAC systems, of which energy consumption is calculated using DIN V 18599-5 and DIN V 18599-7, are summarized. Components supplying heat to or removing heat from rooms are grouped into air handling units, convective heating or cooling equipment (induction units, fan coils, air heaters, etc.) and static (radiant) heating or cooling equipment. For air handling units, recirculated air is also taken into consideration as a medium for heat transportation, but larger air recirculation across plural rooms does not seem to be highlighted.

Table 41 Categories of HVAC systems in national calculation methodologies
(a) DIN V 18599 (space heating and cooling dealt with by DIN V 18599-5 and DIN V 18599-7, respectively)

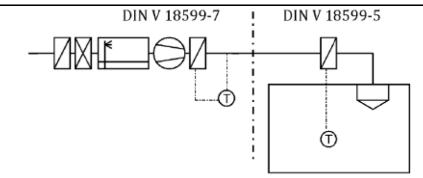
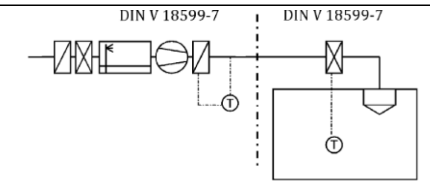
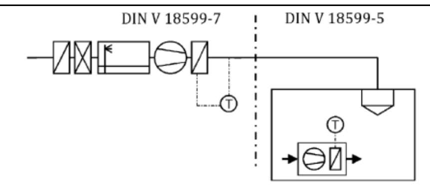
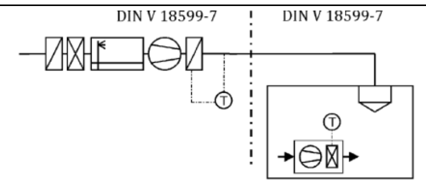
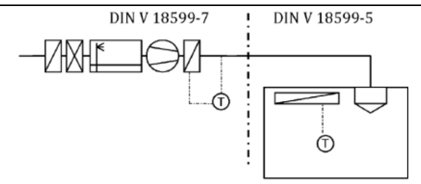
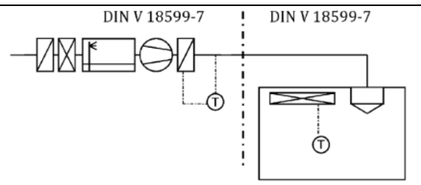
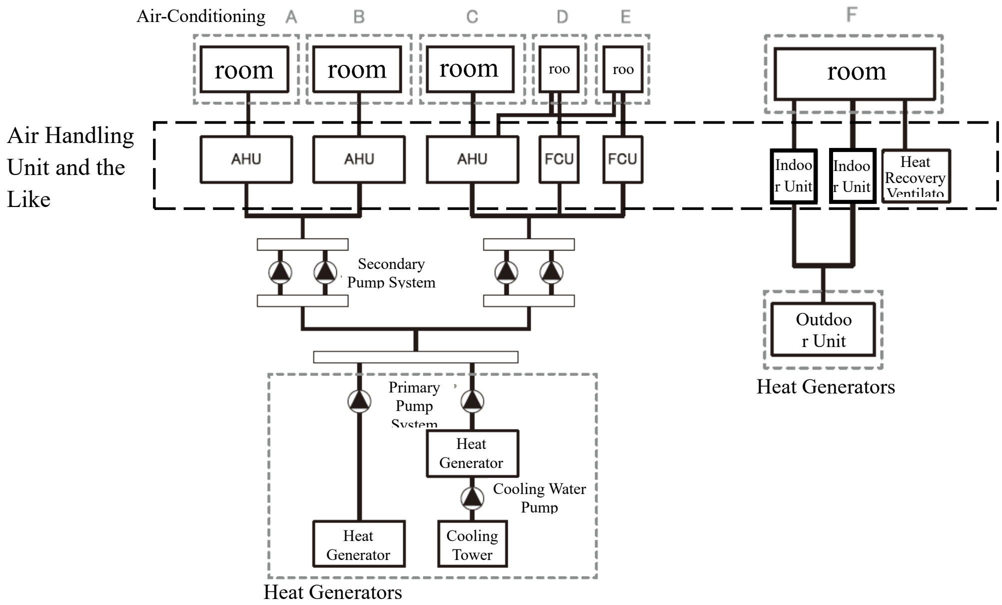
Reheating in the supply air to room temperature (see DIN V 18599-5) Preheating and reheating of the outside air (including recirculated air) in the air conditioner (see DIN V 18599-7) Fan current requirement (see DIN V 18599-3)	
After-cooling in the supply air to room temperature (see DIN V 18599-7) Main cooling of the outside air (including recirculated-air proportion) in the air-conditioning unit (see DIN V 18599-7) Fan current requirement (see DIN V 18599-3)	
Convective heating in the zone with induction units, fan coils, air heaters, etc. according to room temperature (see DIN V 18599-5). Fan flow requirement of recirculation fans (see DIN V 18599-5). Preheating and reheating of the outside air (including recirculated air) in the air conditioner (see DIN V 18599-7). Fan current requirement central air conditioning unit (see DIN V 18599-3)	
Convective cooling in the zone with induction units, fan coil units, air heaters, etc. according to room temperature (see DIN V 18599-7). Fan current requirement of recirculation fans (see DIN V 18599-7). Main cooling of the outside air (including recirculated air) in the air conditioner (see DIN V 18599-7). Fan current requirement central air conditioning unit (see DIN V 18599-3)	
Static heating in the zone with convectors, electric blankets, underfloor heating, component activation etc. according to room temperature (see DIN V 18599-5). Preheating and reheating of the outside air (including recirculated air) in the air conditioner (see DIN V 18599-7). Fan current requirement central air conditioning unit (see DIN V 18599-3)	
Static cooling in the zone with convectors, cooling ceiling, floor cooling, component activation, etc. according to room temperature (see DIN V 18599-7). Preheating and reheating of the outside air (including recirculated air) in the air conditioner (see DIN V 18599-7). Fan current requirement central air conditioning unit (see DIN V 18599-3)	

Table 41 Categories of HVAC systems in national calculation methodologies

(b) <u>BECS</u>

Configurations of typical space heating and cooling systems:



Types of "Air Handling Unit and the Like":

Type	Examples
Air handling unit	Air handling unit, Air handling unit for outdoor air intake, etc.
Fan coil unit	Fan coil unit, Fan convector, etc.
Indoor unit	Indoor unit of variable refrigerant flow multi-split equipment
Energy recovery ventilator	Ventilation unit with energy/heat recovery
Fan	Supply fan unit, exhaust fan unit, etc.
Radiator	Radiator, etc.
Ceiling radiant panel	Ceiling radian panel, Floor heating panel, etc.

Types of Heat Generators in BECS:

Groups	Types
Air heat source	•Air Source Heat Pump •Air Source Heat Pump for Ice Storage • Air Source Heat Pump with Compressor Number Control • Air Source Heat Pump with Compressor Number Control for Ice Storage •VRF (Gas) •VRF(LPG) •VRF(Electricity) •Room Air Conditioner
Water heat source	•Water Cooled Screw Chiller •Water Cooled Screw Chiller for Ice Storage •Water Cooled Scroll Chiller •Water Cooled Scroll Chiller for Ice Storage •Turbo Chiller •Inverter Turbo Chiller •Brine Turbo Chiller at Ice Storage •Brine Turbo Chiller at Chasing Operation •Absorption Chiller (Gas) •Absorption Chiller (LPG) •Absorption Chiller (Heavy-oil) •Absorption Chiller (Kerosene) •Steam Absorption Chiller •Hot Water Absorption Chiller
Combustion	•Small-sized Once-through Boiler (Gas) • Small-sized Once-through Boiler (LPG) • Small-sized Once-through Boiler (Heavy-oil) • Small-sized Once-through Boiler (Kerosene) • Vacuum Hot Water Heater (Gas) • Vacuum Hot Water Heater (LPG) • Vacuum Hot Water Heater (Heavy-oil) • Vacuum Hot Water Heater (Kerosene) •Forced-flow room heater (Gas) •Forced-flow room heater (LPG) •Forced-flow room heater (Kerosene)
Others	•District Heating and Cooling (Cold water) • District Heating and Cooling (Hot water) • District Heating and Cooling (Steam) •Heat Exchanger

Table 41 Categories of HVAC systems in national calculation methodologies
(c) <u>SIA 382/1</u>
System types of ventilation and air conditioning systems by function

	Plant type	Supply air	Exhaust air conveyance	Heat recovery / Waste heat recovery	Filtering the supply air	Heat	Cool	Humidifi-cation	Dehumidifi-cation
	Simple supply air system	X	-	-	X	-	-	-	-
	Supply air system with air heating	X	-	-	X	X	-	-	-
	Simple exhaust system	-	X	-	-	-	-	-	-
	Exhaust system with waste heat recovery	-	X	X	-	-	-	-	-
Ventilation system	Simple ventilation system	X	X	X	X	-	-	-	-
	Ventilation system with air heating	X	X	X	X	X	-	-	-
	Ventilation system with air heating and humidification	X	X	X	X	X	-	X	-
air conditionin	Simple air conditioning	X	X	X	X	X	X	-	(X)
	Air conditioning with humidification	X	X	X	X	X	X	X	(X)
	Air conditioning with humidification and dehumidification	X	X	X	X	X	X	X	X

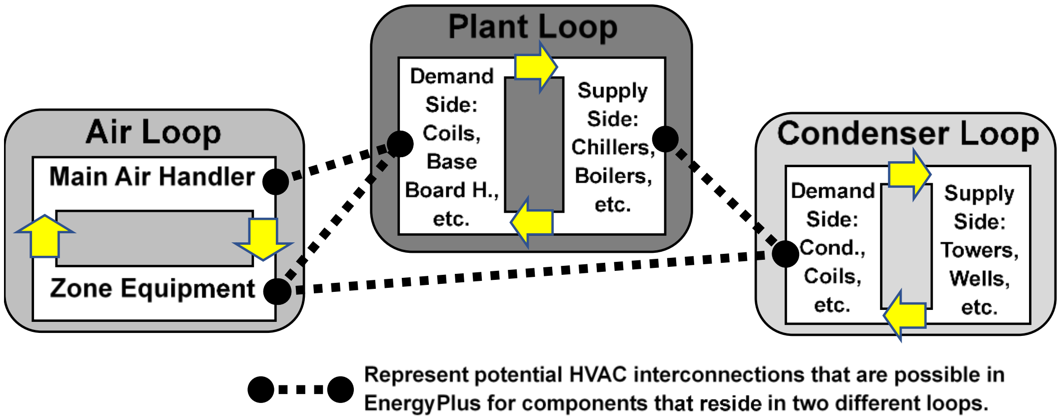
Note: - not influenced by the system or not possible or not available
X controlled by the system and compliance with the corresponding guaranteed values in the room
(X) influenced by the system, but without guaranteed values in the room

Table 41 Categories of HVAC systems in national calculation methodologies
(d) <u>SBEM</u>
Types of space heating and cooling systems (26 categories):
• Central heating using water: radiators • Central heating using water: convectors /
• Central heating using water: floor heating • Central heating with air distribution
• Other local room heater - fanned • Other local room heater - unfanned
• Un-flued radiant heater • Flued radiant heater • Multi-burner radiant heaters
• Flued forced-convection air heaters • Un-flued forced-convection air heaters • Single-duct VAV • Dual-duct VAV • Indoor packaged cabinet (VAV) • Fan coil systems • Induction system
• Constant volume system (fixed fresh air rate) • Constant volume system (variable fresh air rate)
• Multizone (hot deck/cold deck) • Terminal reheat (constant volume) • Dual duct (constant volume)
• Chilled ceilings or passive chilled beams and displacement ventilation • Active chilled beams
• Water loop heat pump • Split or multi-split system • Single room cooling system

In SIA 2044 (Section 2.4.1.5), even though recirculated air can be taken into account in the calculation of fan energy use, the recirculated air is not accounted for in the standard calculation method. In SIA 382/2 (Section 4.2.4.2), the following interesting viewpoint of HVAC systems is described.
"The use of air as a heat transfer medium is inefficient and requires a lot of energy. The use of mechanically conveyed air over the hygienically necessary volumetric flow is therefore discouraged. Air-

based systems for cooling are useful only for uses in which the heat load is mainly defined by the heat emission of the people.”

In the description of “high velocity forced-convection air heating (induction nozzle system)” (Section 3.5.2 “Defining HVAC Systems” of iSBEM User Guide 2), the minimum flow rate guidelines given for destratification systems are mentioned. They provide critical guidance in order to avoid temperature stratification due to forced air heating.



Main Air Handler:
Unitary Systems,
Forced-Air Furnace and Central Air Conditioning,
Unitary Systems with Changeover-Bypass-Variable Air Volume,
Unitary Air-To-Air Heat Pump,
Unitary Multi-Speed Air-To-Air Heat Pump,
DX (Direct Expansion) Cooling/Heating Package,
Desiccant Dehumidifier Package,
Unitary Water-To-Air Heat Pump

Zone Equipment:
Air Distribution Terminal Unit,
Air Terminal Single Duct Mixer,
Fan Coil Unit,
Window Air Conditioner,
Packaged Terminal Air Conditioner,
Packaged Terminal Heat Pump,
Zone Single Speed Water-To-Air Heat Pump,
Zone Air DX Dehumidifier,
Energy Recovery Ventilator,
Variable Refrigerant Flow Terminal Unit,
Unit Heater,
Unit Ventilator,
Zone Exhaust Fan,
…

Plant Loop / Supply Side:
Boilers (Simple Hot Water Boiler, Steam Boiler),
Chillers (Absorption Chiller, Combustion Turbine Chiller, Engine Driven Chiller, Electric Chiller, etc.),
Plant Loop / Demand Side:
Air Cooled DX Air Conditioner,
Variable Speed Unitary Air Conditioner / Air-To-Air Heat Pump,
Electric / Fuel-Fired Heating Coil,
Electric and Gas Air Heating Coil,
Variable Refrigerant Flow Heat Pumps,
…

Figure 17 Connections Between the HVAC Simulation Loops and Half-Loops (EnergyPlus[19])

[19] This figure is made based on Figure 9.1 and relevant descriptions in Engineering Reference (EnergyPlus Version 9.2.0 documentation).

In EnergyPlus, HVAC systems are grouped and described based on the three Loops (Air, Plant and Condenser) as shown in Figure 17. A typical central forced air HVAC system and its main components are described by the three Loops, but there are HVAC systems, of which components cannot be divided into the three Loops and extend over two Loops, such as a window air conditioner, which includes all three Loops inside the equipment. It seems that the descriptions of HVAC systems in the EnergyPlus document are most comprehensive and accurate.

7.3 Determination of Ventilation Rate Including when Demand Controls are Applied

The amount of outdoor air intake is one of the most influential factors on the space heating and cooling needs, which is reflected on energy use for those purposes. It is also influential on fan energy use. Therefore, a more accurate estimation of the actual ventilation rate is important for energy calculation methodologies. However, the actual ventilation rate is dependent on fan specifications (pressure-flow rate characteristic and efficiency) and duct system (length, thickness, bend, etc.). It should be noted that only their design values, which are described in design documents of the evaluated building, are usually available for energy calculations, as it is almost impossible to carry out detailed pressure loss calculations by energy calculation methodologies for compliance checking, which need very detailed specifications and information on duct system configuration. When plural branches of duct exist in a ventilation system, each airflow rate of the branches is hardly described and only the total airflow rate is usually described as a design value. In addition, depending on the framework of policies, energy calculations for compliance checking are often carried out before construction works commences, and it is very difficult to use measured values in the calculation for compliance checking.

On the other hand, assumptions on the outdoor air supply to each category of space usage (such as “office room”, “meeting room”, etc.) and its schedule are prepared as a database for most national energy calculation methodologies, and it is probable that these assumptions may be different from the design values in actual buildings to be evaluated. However, such assumed values, which are usually determined to comply with ventilation requirements such as in national regulations or standards, are convenient as default values used for energy calculation. For example, fan energy use can be calculated by multiplying the default values for ventilation rate and fan system efficiency such as Specific Fan Power (SFP), which can be estimated by using designed fan power (input) and airflow rate.

Therefore, there are two options for determining input values for outdoor air intake, either the design values for the evaluated building or the assumptions for outdoor air intake included in the schedule and condition of space usage as default assumptions.

The demand control of the ventilation rate is a promising technique for energy saving, which determines current ventilation requirement by monitoring any index of indoor air pollution (e.g., CO_2 for habitable room, CO for parking garage) and regulates the outdoor intake. Some calculation methodologies can evaluate the effectiveness of the demand control. However, the reduction rate of the ventilation rate depends on the margin of the capacity of the ventilation system compared with the maximum density of occupants and its time variation.

If a common HVAC system deals with both thermal environment and indoor air quality in multiple rooms divided by partition walls, the design of the HVAC system should be implemented carefully so as not to sacrifice either of the environmental aspects. The effectiveness of such demand control ventilation in energy saving might have to be limited such as to the cases in which served rooms have similar conditions and schedule of room usage. As such, there is still a need for a clearer HVAC system design with demand control function for multiple rooms. This also suggests that the calculation method evaluating the effectiveness of the demand control ventilation should limit its target to only design methods with clear definitions and standards such as on configuration of HVAC systems, locations of sensor and control algorisms. There seems to be a strong need for more detailed design guidelines for HVAC systems.

7.4 Representation of Energy Efficiencies of Heat Sources Including Sizing, Partial Load Effect and Control of Multiple Generators

The rationale and algorithms for calculating final energy use by heat and cold generators varies from nation to nation. In European countries, there are three approaches applied on monthly heating and cooling needs (demands) calculation.

One uses seasonally integrated values for energy efficiency of generators, such as SEER in SBEM. The seasonally integrated values are determined beforehand for each kind of heat and cold generators.

The second directly uses test results of generators, namely EER values according to EN 14825. In UNI/TS 11300 series, four EER values, curves for the condition of lower part load factor and coefficients representing other actual conditions of the generator are used to evaluate actual energy efficiency.

In DIN V 18955-7, for cold generators, EER at rated condition (100%) is used with the part load values (PLV_{av}), which are given in the tables for different conditions of the following parameters; generator type, refrigerant, control of generator and cooling tower, specifications on connected AHU and heat recovery unit and room type serviced by the cold generator. Table 42 summarizes the technique to calculate energy use by cold generators in three monthly energy calculation methods.

Table 42 Analysis of National Calculation Methodologies on Energy Use by Cold Generator for Space Cooling (monthly calculation methods)

<table>
<tr><th colspan="2"></th><th>Italy
UNI/TS11300-3</th><th>Germany
DIN V 18599-7</th><th>UK
SBEM</th></tr>
<tr><td colspan="2">(a) Grouping of cold generators</td><td>Compressor type or absorption type</td><td>Electrical compressor type, absorption type or gas engine compressor</td><td>Air/Water cooled chiller, Remote condenser chiller, Heat pump (electric/gas/oil)</td></tr>
<tr><td colspan="2">(b) Main input parameters and relevant standard(s)</td><td>Compressor type: EER_{100} (Energy Efficiency Ratio at 100% partial load ratio), EER_{75}, EER_{50}, EER_{25} (EN 14825), correction coefficients, η_1 for temperature. conditions. If EERs at partial loads are not available, EER_{100} can represent.
Absorption type: GUE (rated efficiency, EN 12309), correction coefficients, C_d for partial loads.</td><td>Compressor type: EER or ζ (heat ratio) at rated condition, generator type, refrigerant, control of generator and cooling tower, specifications on connected AHU and heat recovery unit, room type serviced by the cold generator
Gas engine compressor: Values of EER and PLV_{av} are fixed.</td><td>Nominal electrical power in kW in case of chiller. Qualification for the ETL (Energy Tech. List) for a government scheme called ECA (Enhanced Capital Scheme), which determines default values of SEER. If only the full load efficiency (EER_{100}) measured according to EN 14511 is available, SEER=EER_{100}. If the full and half (50%) load EERs are known, SEER is the average of the EERs. If the part load EERs at four points, SEER is the average of the four EERs. For application in an office, $SEER=0.03\times EER_{100}+0.33\times EER_{75}+0.41\times EER_{50}+0.23\times EER_{25}$.</td></tr>
<tr><td colspan="2">(c) Core logic for calculating energy use by the generators</td><td>Compression type: Using EER values corrected by η_1, the energy efficiency at the monthly averaged partial load factor is obtained by interpolation.
Absorption type: Multiplying GUE with C_d, the efficiency is obtained.
Monthly average efficiency η_{mmk} is calculated by equation (14).</td><td>Energy use = Cooling energy need × EER × PLV_{av}. The PLV_{av} (Part load value) can be determined by referring to specifications of the HVAC system listed above. The tables for PLV_{av} are given in the Appendix B of DIN V 18599-7. This method is called as “characteristic value method”.</td><td>The cooling energy use for each cold generator (C_e) is calculated by the equation: $C_e=C_d/SSEER$, where C_d is the addition of the cooling demand of all zones serviced by the cold generator, and SSEER (system seasonal energy efficiency ratio) is the ratio of the total cooling demand in spaces served by the cold generator divided by the energy use into the cold generator. The SSEER can be calculated from SEER and heat loss through pipework and duct work as well as duct leakage.</td></tr>
<tr><td rowspan="2">(d) Standard</td><td>calculation</td><td>UNI/TS11300-3</td><td>DIN V 18599-7</td><td>EN 15243</td></tr>
<tr><td>equipment</td><td>EN 14511, EN 14825, EN 12309</td><td>EN 14511, EN 14825</td><td>EN 14511</td></tr>
</table>

Table 42 (continued from the previous page) Analysis of National Calculation Methodologies on Energy Use by Cold Generator for Space Cooling (hourly calculation methods)

		Switzerland SIA 2044	Japan BECS (Web-program)	USA EnergyPlus
(a) Grouping of cold generators		Chiller (Electrically driven)	Air/Water cooled heat pump/chiller/refrigerator, Package air-conditioner See Table 41 (b).	Air/Water cooled chiller (models based on fluid temperature difference, etc.), Absorption chiller, etc. See Figure 17.
(b) Main input parameters and relevant standard(s)		$\eta_{COP,C}$ (energy efficiency for cooling) and temperatures of cold and cooling water, which are measured at four different partial load ratios. $\eta_{COP,C}$ (energy efficiency) and temperatures of cold and cooling water, which are measured at one of the four different partial load ratios, but with different cooling water temperature. Parameters are measured according to ARI or ESEER.	The rated energy efficiency of cold generator, which is measured according to the test standard of the cold generator, (see (e)) thermal need dealt with by the cold generator and outdoor temperature at the time. The following characteristics of each cold generator are assumed; 1) relationship between the maximum output (capacity of the generator) and outdoor (or cooling water) temperature, 2) relationship between the maximum input (energy use) and outdoor (or cooling water) temperature and 3) relationship between input (energy use) ratio and part load ratio.	See 5.7.7.1 equations (33) to (38): nominal capacity, nominal COP, rated air/water temperature entering the condenser, rated water temp. leaving the evaporator, required air/water temp. entering the cond. to maintain rated capacity, required water temp. leaving the evaporator to maintain rated capacity, design air/water temp. entering the cond., design water temp. leaving evaporator, current air/water temp. entering the condenser and current water temp. leaving the evaporator.
(c) Core logic for calculating energy use by the generators		Based on EN 16798-13, a function of $\eta_{COP,C}$ (energy efficiency) with temperature conditions and partial load ratio as independent variables is determined by the regression analysis. By using the function, $\eta_{COP,C}$ (energy efficiency) can be determined for any part load ratio and temperature conditions, as shown in the equation (16).	The part load ratio is calculated as the ratio of the cooling energy need dealt with by the cold generator divided by the maximum output under the outdoor (or cooling water) temperature. By using the relationship between the part load ratio and the input (energy use) ratio, and the relationship between the maximum input (energy use) ratio and the outdoor (or cooling water) temperature, the input (energy use) at the time can be calculated.	Power consumption is calculated by equations (33) to (38).
(d) Standard	calculation	EN 16798-13	-	Engineering Reference
	equipment	ARI (the latest version is AHRI 550/590-2018), ESEER	e.g., JIS B 8613 for water chilling unit, JIS B 8621 for turbo centrifugal water chillers	AHRI 550/590-2018 or AHRI 551/591-2018

In SIA 2044, a very sophisticated method is used, but this needs very detailed test results for cold generators. In BECS, multiple EER values are not used, and the energy efficiency of generators only at the rated condition and curves representing the influence of partial load factor and air/water temperatures for each of generator types are used to evaluate hourly energy efficiency of generators. The curves are based on theories and are adjusted by referring to the results of field measurement in actual buildings.

The way how the energy use by heat and cold generators is calculated is very much influential on the total energy use for space heating and cooling or HVAC systems. Needless to say, it is because the percentage of the energy use by the heat and cold generator seems to be the largest one. Therefore, there seems to be a strong need for improving and validating accuracy of the calculation methodologies to predict actual energy use by heat and cold generators. The need includes much more data collection of actual behavior of the heat and cold generators, which should be used for further technological development. Especially actual energy use and heat and cold generation in lower partial load conditions such as 10-30% should be studied more intensively.

7.5 HVAC components sizing calculation tools integrated in the energy calculation methodologies

As shown in Table 42 for cold generators, every energy calculation methodology is eager to deal with the influence of part load operation on generators' efficiency. It seems because margins between generators' capacity and distributions of heating and cooling needs (demands, loads) are critically influential on actual energy efficiency of the generators. It does not mean at all that any limit design is worth considering, but it means energy efficiency under partial load conditions and other actual conditions such as of outdoor air temperature should be paid attention and countermeasures to improve the actual energy efficiency should be searched for.

Among three methodologies adopting hourly calculation, SIA 2044 and EnergyPlus cover a function of estimating expected maximum heating and cooling needs, not only for heat and cold generators, but also for other components of HVAC systems, such as coils, fans and pumps.

In Chapter 2.3 of SIA 2044, a hourly calculation method of the required heating and air conditioning (cooling) capacity is prescribed. In addition, in Chapter 3.1 of SIA 382/2, another method to design heating systems for rooms is quoted from SIA 384.201, which was superseded by EN 12831-1:2017.

In Chapter 10 of Engineering Reference of EnergyPlus, methods for sizing of loop (see Figure 17 in 7.2) and equipment are described. EnergyPlus follows the heat balance method[20], which is the current industry standard method for calculating space loads.

[20] This method is contained in ASHRAE Handbook-Fundamentals (chapter 18 in 2013 edition). It is said that the heat balance method is not new and many energy calculation programs have used it in some form for many years.

7.6 Representation of Energy Efficiencies of Air and Water Conveyance Including Sizing, Partial Load Effect and Control of Fans and Pumps

The influence of HVAC system controls on their energy performance should not be neglected, but it is still very difficult to clearly define various kinds of control methods and to evaluate value setting of key parameters in the control methods. A calculation method clearly states that ideal control functions are assumed (Chapter 1, DIN V 18599-3:2016), and another calculation method (BECS) adopts a more cautious evaluation (safety-side evaluation) for components affected by the controls, when the logic of the control strategies is not clearly defined.

Even though HVAC system control logic is very influential on energy performance, it has been rather difficult to standardize the control and its logic. Figure 18 shows that a clearer definition of the control of plural secondary pumps operated depending on water flow rate can differentiate the energy performance of control logics.

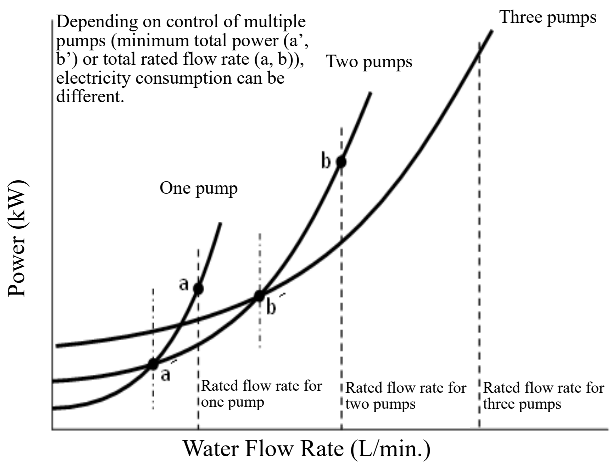


Figure 18 An example of the influence of delicate difference of control on the amount of energy use (control of multiple pumps to reduce their electrical power)

ASHRAE Guidelines 36-2018 High-Performance Sequences of Operation for HVAC Systems provides uniform sequences of operation for HVAC systems that are intended to maximize the systems' energy efficiency and performance, to provide control stability and to allow for real-time fault detection and diagnostics. This guidelines is valuable as one of the detailed design standards of HVAC system. There seems to be a strong need for this kind of detailed and concrete design guidelines for HVAC systems and their control logics.

Any calculation methodologies reviewed in this report do not have a clear list and definitions of control methods for supply and any other fans of air handling units (VAV controls) nor for secondary pump systems (VWV controls). The amount of their energy use is as large as that of heat generators in buildings. The sizing for fans and pumps is critical, and the relationship between controllable minimum speed of motors and actual partial load ratio of the fans and pumps is also critical. However, it is still very difficult to evaluate such aspects of the design and relevant initial commissioning practices in the HVAC energy calculation methodologies.

The energy efficiency of motor systems is another critical issue in the estimation of fan and pump energy use. It includes motors and variable frequency drive (VFD) and inverters. The dependency of energy efficiency of the system on its partial load ratio makes the issue more complex.

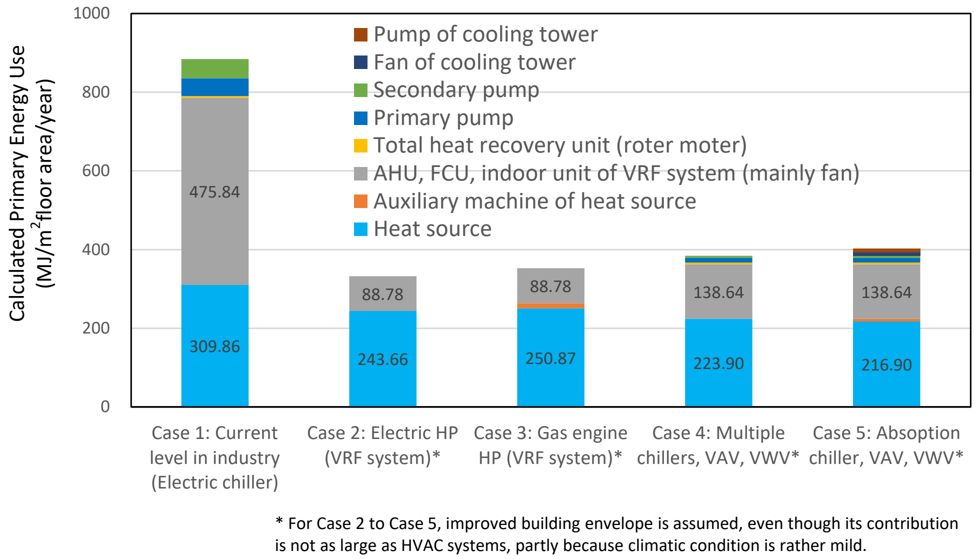


Figure 19 An example of HVAC energy calculations for four energy efficient cases (Case 2 to Case 5) compared with target energy use (criterion of building energy standard compliance)[21]

An example of HVAC energy calculations is shown in Figure 19. Compared with VRF systems that use refrigerant pipes connecting outdoor unit (heat source) and multiple indoor units (Case 2 and Case 3), central HVAC systems with air handling units tended to consume much more energy for fans. Main difference between Case 1 and Case 4/5 was implementation of sizing in compliance with a design standard and existence of VAV control (only constant static pressure control), and the average part load ratio of fans of the air handling unit was 0.34 and 0.28 for cooling and heating, respectively. This result is just an example that shows the importance of realistic quantification of fan energy use in HVAC systems.

7.7 Consideration of Commissioning and Initial Adjustment of HVAC Systems

For central HVAC systems, the initial adjustment of the systems before they are first used is critical, even though the time and resource available for carrying out the initial adjustment is sometimes limited during busy construction practices. A clear definition of necessary initial adjustment for any HVAC subsystems and components is still difficult to find in national energy calculation methodologies and relevant documents. Even though finding a relevant description is very rare, a calculation method (Section 6.5.2.6 of DIN V 18599-7) defines a coefficient to differentiate between whether the initial adjustment has or has not taken

[21] This calculation is done by BECS (see Section 5.4) for an office building with 7 floors and 10,358m^2 total floor area in Tokyo (mild winter and hot/humid summer). In Case 2 to Case 5, sizing of AHU, FCU, indoor unit of VRF system, pump and heat source including cooling tower has been done in compliance with the Design Standard of Building Services supervised by Government Buildings Department, Ministry of Land, Infrastructure, Transport and Tourism. The Design Standard is most frequently referred to in Japanese practices.

place. A correction factor for hydraulic adjustment (f_{Abgl}) is applied in the calculation method of pump energy use, and if the hydraulic adjustment for pipes is carried out, f_{Abgl}=1.0, otherwise f_{Abgl}=1.25.
Even after reasonable sizing practices, it is natural that the system still has the enough allowance of capacities in order to securely deal with the requirement to the system. Therefore, ideally, the outputs of motors of fans and pumps should be adjusted by using variable frequency drive (inverter) in parallel with balancing practices. However, in the early design stage before starting construction, it is impossible to know the result of the adjustment and measured value of electric power.

7.8 Categories of Building and Space for Schedule and Condition of Usage

A sort pf schedule and condition for space usage in buildings has been mainly used for sizing HVAC systems including heat generators and air/water conveyance, as well as for sizing domestic hot water systems. For the purposes of sizing, the schedules and condition have been determined as extreme conditions such as the largest possible internal heat gains by electric appliances and lighting equipment for the sizing of space cooling systems. The capacity of ventilation systems for outdoor air supply is determined by assuming the largest possible density of occupants. However, in the energy calculation in order to evaluate building energy performance and how much energy can be saved by applying focused techniques, actual realistic schedule and condition is needed rather than extreme ones. There is a necessity to further study the schedule and condition of building and room usage, partly because of variety of non-residential buildings. There are relevant standards, ISO 18523-1:2016 “Energy performance of buildings - Schedule and condition of building, zone and space usage for energy calculation - Part 1: Non-residential buildings” and ISO 18523-2:2018 “Energy performance of buildings - Schedule and condition of building, zone and space usage for energy calculation - Part 2: Residential buildings”.

As for buildings for rent, it can be difficult to determine how their rooms will be used when the buildings are still at design or construction stages. In that case, any rule on what categories of room should be assumed or if it is necessary to carry out the energy calculation again when the tenants are fixed.

7.9 Referenced Standards for Test and Design of Components and Portions

The test standards and performance indices, which are referred to by energy need calculations for the building envelope, are much more clearly and well defined than those for HVAC system components.
On the contrary, a consensus on which standards for testing generators and calculating the performance indices should be used and referred to has not yet been achieved among national energy calculation methodologies. The decision should be made on the basis of the observation of the process, which proves that the actual behaviour of the evaluated generator can be simulated correctly by using the appropriate indices based on the standards for testing and calculating the indices. This should not only consider the product standards for testing and calculating indices representing product’s energy performance, but also how and by whom the tests are carried out and the results are presented is important in order to maintain reliability of the energy calculation.

It can be said that calculations in national energy calculation methodologies are rather simple and more detailed and sophisticated calculation might be needed before developing more simple and practical calculation methods such as for the national calculation methodologies. ASHRAE Standard 205P "Standard Representation of Performance Simulation Data for HVAC&R and Other Facility Equipment", which is under review at present, aims at facilitating sharing of equipment characteristics, which are much more detailed than indices for energy efficiency prescribed by HVAC products' standards.

7.10 Techniques to Simplify the Preparation of Input Data

Most national building energy calculation methodologies are used for so-called mandatory regulations. Availability of detailed design information depends on when the calculation is to be carried out for compliance checking. If it is carried out before starting construction in order to obtain permission to build, it is possible that full specifications of the building envelope and energy systems have not yet been finalized and there is room for change during the construction phase. In the case of large buildings, the construction phase can be a very long term and changes of the design usually occur. If the calculation methodologies need too detailed and specific input data, the possibility of recalculation is increased. Therefore, simplification of input data is inevitable to some extent, even though there is a necessity to make the calculation more accurate and reliable on the other hand. This point may make a difference between calculation methodologies for building energy codes to be strictly complied with and for voluntary design optimization. For the latter purpose, there may be an opinion that calculation methodologies other than national ones for regulations work well enough and it is not necessary to try to apply national ones for the voluntary design optimization. One advantage of utilizing the basis for the national energy calculation methodologies may be their unbiasedness to various techniques for energy saving and transparency of their calculation algorithms.

Simplified calculation methods, which is suitable for national regulations and certification systems, can be utilized for making decisions in early stage of design process. However, a national energy calculation methodology gives a caution to users not to use them for design purposes.

There is still much room for discussion on the simplification of national energy calculation methodologies.

7.11 Completeness of Documentation on the Calculation Rationale and Algorithm

The development of energy calculation methodologies seems to be much more concrete and quantitative project than writing textbooks on energy saving techniques in more qualitative manners. Analysis of physical phenomena such as heat transmission and air movement due to buoyancy could be described clearly, but phenomena containing the behaviour of machine controlled by any logic are not easy to be analysed and described. That is one of the reasons why the energy calculation methodologies need the help of product (machine) standards including testing protocols, by which a part of the physical phenomena around the machine could be understood and predicted. However, the building energy systems consist of many and various machines and the way of their combination and selection could be a part of the culture of national HVAC industries, and it might be difficult to standardize the way of design building energy systems. By overcoming such challenges, national and international standards on the building energy calculation methodologies especially for HVAC systems have been developed and have supplied rather complete documentation on the calculation procedures. The documentation and transparency of calculation logics seems to be the only way to make the calculation methodologies evolve to be more reliable and easier to use in practices.

7.12 Information on Calculation Process Validation

The development and operation of national calculation methodologies needs significant resource from public and private budgets and manpower. Not only for initial development but also for regular revisions, tremendous investment is indispensable, and it is believed that the investment is the most efficient one to realize a rapid transformation toward zero energy and carbon neutral buildings. Its final objective is clearly the reduction of CO_2 emission due to energy use in buildings. It is one of the most promising ways to accumulate the robust algorithms for differentiating the effectiveness of each evaluated technique in regards to improving energy efficiencies, even though we have hoped for firmer proofs that the energy calculation methods can differentiate total energy efficiencies of buildings. In the near future, collecting samples with calculated energy use and actual energy use after starting the use of buildings should be attempted. There are some trials to compare calculated and actual energy uses for residential buildings, but it is still very rare to find such comparisons especially for non-residential buildings. It may be a little early to proceed to the validation stage in non-residential cases.

Before realizing such overall comparison between calculated and actual energy use, there is a strong need for data useful for validating parts of energy calculation methodologies. In ASHRAE Standard 140-2017 “Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs”, data useful for validating programs has been accumulated, and a set of data for central HVAC systems with air distribution components has been included. However, there is still a strong need for data and protocol for validation of energy calculation methodologies.

8. Analysis

8.1 Differentiation or Integration between Calculation Methodologies for Compliance Checking and Design Practice

In some national calculation methods documents, there are declarations of the main purpose of developing them. A certain document clearly advices not to utilize the calculation method for design purposes, and states that the main purpose of the method is checking compliance with the regulation. Another document includes a method to determine capacity of equipment such as of heat and cold generators, and tries to promote utilization in design practice.

It is probably better that one calculation method can be used for both of compliance checking and decision making on building and system design. Even for design practices, simpler calculation methods and limited requirement for input data as being done for compliance checking are convenient especially for decision making in early design stage. However, there is a risk for any kind of calculation methods that they may guide users to draw wrong decisions, because assumptions behind the calculations or default values in the calculations may not be suitable for certain design and project conditions. The cautious application of the calculation methods should be recommended, and they should be used for design practices in users' own responsibility. It is recommended that the calculation methods should be transparent with full documentation for their logics and rationale as completely as possible, and validation by third persons should be promoted. Any intentional black boxes and taboos for criticisms should not be left.

8.2 Time Interval of Calculation

A monthly calculation is used in DIN V 18599, UNI/TS 11300 and SBEM. The monthly calculation method of heating and cooling needs (demands) has been based on ISO 13790, which is revised with new number ISO 52016. Swiss national calculation methods based on SIA standards has adopted hourly calculation, and BECS has basically adopted daily calculation of heating and cooling needs, which are allocated evenly to operating hours to produce hourly needs. ASHRAE 90.1 includes compliance approaches by using computer-based simulation programs capable of hourly calculation. The barrier for transition from monthly calculation to more detailed calculation such as hourly one is not power of computers but the amount of time and labor for preparing programs and documents as well as unfamiliarity of users. When the hourly calculation is installed in the programs, information on sizing of equipment can be more easily included in calculation results by using appropriate assumptions on condition and schedule of building and room usage.

Triggered by the new European Directive on Energy Performance of Buildings (EPBD 2018) and by the need to take into account innovative technologies in low energy buildings, many European countries are in the process of revising their national methodologies, to bring them more in line with the new versions of the ISO-CEN EPB standards. Several of these countries (e.g. Italy) are preparing a change from monthly to hourly calculation method. This is facilitated by (EN) ISO 52016-1 that enables to calculate the hourly energy needs for heating and cooling, internal temperatures and sensible and latent heat loads with no more input data than needed for the monthly calculation method.

8.3 Classification of HVAC Systems as Objectives of Energy Calculation

The way to classify HVAC systems and their names in terminologies is not internationally standardized. Even the terminology "HVAC" seems to be a regional expression of the machines for that specific purpose. In European documents, the term "ventilation" includes a cooling function. It might be partly because of cultural and social aspect of national relevant industries, as well as because of climatic conditions. In central Europe, summer climate is typically mild and dry in comparison with Asia-Pacific regions and North America, and space cooling has not spread much widely. The combination of hot water space heating system and all fresh air cooling seems to be dominant, when space cooling is installed in non-residential buildings. On the contrary, in Asian-Pacific regions and some parts of North America, HVAC systems are used for both of heating and cooling.

In order to interpret and understand each national calculation methodologies, information on national practices of HVAC system design, construction and initial adjustment (as a part of commissioning) should be collected further, and should be analyzed to provide a basis for much clearer understanding of the national calculation methodologies. Therefore, in addition to documents on the calculation methodologies, national standards especially for designing HVAC systems should be focused in the future.

8.4 Energy Efficiency of Heat and Cold Generators

The energy efficiency of heat and cold generators (i.e., chiller, refrigerator, etc.) depends on partial load ratio, which is the ratio of load at each time to the full capacity of the generators. If the heat and cold generator is electrical compressor type equipment and heat pump, the highest energy efficiency is usually obtained at around intermediate partial load ratio such as 40-60%. When the partial load ratio is very low such as 10-30%, most of the heat and cold generators including variable capacity type work intermittently, namely periodically run and stop. Such intermittent operation may deteriorate energy efficiency of heat and cold generators, considerably. The energy efficiency also depends on temperature of heat sources such as outdoor air for air-source heat pump and cooling water for water-source heat pump. For example, in case of space heating, if outdoor temperature is much lower than the condition of tests, energy efficiency for higher outdoor temperature even at the same partial load ratio as a test result cannot be obtained in actual situations.

In the calculation of energy use for space heating or cooling, COP (Coefficient of Performance) or EER (Energy Efficiency Ratios) at different partial load ratios and temperature conditions are often focused and utilized. The combination of the partial load ratios and the temperature conditions is usually predetermined as conditions of product tests by assuming a linear relationship between those two factors and the partial load ratio under the severest (coldest or hottest) temperature conditions. For example, in EN 14825, part load conditions for air-to-air units for cooling are (A) 100% partial load ratio at 35 °C (the hottest condition), (B) 74% partial load ratio at 30 °C, (C) 47% partial load ratio at 25 °C, (D) 21% partial load ratio at 20 °C (the mildest condition). In this case, it is assumed that the capacity of the evaluated cold generator is equal to the maximum cooling need, and the assumption is irrelevant to actual sizing practice for evaluated buildings. In addition, depending on the sizing in evaluated buildings, low partial load condition may occur even under rather severe temperature conditions.

In the tests of energy efficiency at partial load conditions according to testing standards of compressor type equipment and heat pump, in order to maintain reproducibility of the test results, manufacturers cannot help setting and fixing the status of components of the heat and cold generators, such as compressor speed and valves' opening. However, in actual situations, due to various realistic controls of the machines for failure prevention, it is possible that such stable conditions may not always be maintained and the machines work intermittently. In this meaning, the test results especially for lower partial load ratios should be used carefully in the HVAC energy calculation. It is still very important issue how actual energy efficiency of compressor type equipment and heat pump in lower partial load ratio should be evaluated in order to realize much more realistic HVAC energy calculations. To solve the problem, actual behavior of heat and cold generators should be monitored in real buildings by fully utilizing building energy management systems, and the results should be reflected on further development of relevant calculation methodologies.

8.5 Evaluation of Control Methods for Variable Air Volume and Variable Water Volume

The influence of HVAC system controls on their energy performance should not be neglected, but it is still very difficult to define various kinds of control methods and analyze the influence of value setting of key parameters in the controls. Some energy calculation methodologies clearly state that ideal functions of the controls are assumed, while another adopted a cautious approach in evaluating the components affected by the controls. Such compensations due to lack of information may be inevitable at present.

Especially when recirculated air is used as heat and cold transfer medium between air handling units and rooms, the amount of energy used for fans can be large, and countermeasures to reduce the fan energy by variable air volume systems and variable frequency drives is one of the promising techniques to save energy. There is a strong need for developing much clearer design guidelines or standards to define many promising control strategies, by which much more accurate calculation for energy saving can be approached.

8.6 Accreditation of Calculation Methods Other Than National Calculation Method and Standards

National energy calculation methodologies seem to face challenges in strengthening their credibility and completeness as prediction methods of energy use. To strengthen their credibility and completeness, it is important to validate the calculation methodologies by comparing the results with reference data already verified on the basis of experiment, measurement or authorized simulation. The same reference data can be used for accreditation of calculation methods other than national calculation methodologies.

There are at least two documents which can be used to prove the reliability of calculation methods. They are CIBSE TM33 "Tests for software accreditation and verification" and ANSI/ASHRAE Standard 140 "Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs". For CIBSE TM33, most of the tests for accreditation of programs are for building envelope and the tests for energy systems including HVAC systems are rather limited to the test for the air handling unit, which is just a part of the whole HVAC system. The latest version of ANSI/ASHRAE Standard 140-2018 contains a set of analytical verification test cases for evaluating air-side HVAC equipment models. It should be utilized for validating calculation logics and algorisms for evaluating energy efficiency of fan systems, and there is a strong need for more HVAC system data sets expected to be added in the near future.

Dynamic calculation methods for space heating and cooling needs have been fully developed, sophisticated and validated. In the set of CEN ISO EPB standards, this part is covered by (EN) ISO 52016-1. It contains a fully described hourly calculation method, to ensure unambiguity and to avoid the need of gathering extra input data. A new standard, (EN) ISO 52016-5 is now being developed that will open up the methodology for other dynamic methods, using e.g. ANSI/ASHRAE 140 test cases complemented by reference results and acceptance criteria.

It is necessary to check the logics and algorithms of energy use calculation for the building energy systems in approved software other than national calculation methodologies, and if they are deemed more reliable and useful, they should then be utilized in national calculation methodologies. However, if any country ceased to aim to improve its national energy calculation methodology and completely entrusted the evaluation of building energy performance for regulations to commercially available calculation tools, it would lose the chance to control the reliability of energy calculations.

8.7 A trial to Combine Energy Calculation before Construction and Energy Monitoring under Occupancy

In NABERS (See Section 5.1), an energy calculation by using dynamic simulation software is made in the design stage, and after the construction and occupation of the building measured energy consumption data is assessed. Taking into consideration that after the early stage when the energy calculation is carried out there may be changes from initially assumed equipment and control strategies, the concept called “off-axis model” is adopted to incorporate such changes into the energy calculations. This is a countermeasure to cope with the possible discrepancy between calculated and actual energy consumptions.

8.8 Procedures for Compliance Checking and Energy Performance Certifications

The procedure for compliance checking and certification is outside the scope of this working group activity. However, the building energy calculation methodologies have been developed especially for the procedure for compliance checking and certification, and the possible degree of detail and availability of input data depends on the procedure. In the whole design and construction process, when the calculation has to be done and the correctness of the input data has to be checked must be ruled in building energy codes and regulations. It is not reasonable to assign too heavy work for the calculation and compliance checking on practitioners. Therefore, the degree of detail of the calculation methodologies should be optimized by taking the procedures for compliance checking and certification into consideration.

8.9 Accomplishment by National Calculation Methods for HVAC in Non-residential Buildings

It is too early to compare different national calculation methodologies and definitively evaluate their effectiveness. This is mainly due to the huge quantity of documents, which have to be analyzed in order to reach sufficient understanding of relevant national calculation methodologies. However, at this point, it seems that the developers of national calculation methodologies have been struggling with common challenges caused by the initial experience in developing methods, so that they can be unbiased, transparent, fully documented and usable without excessive burden for practitioners.

9. Conclusions

For compliance checking in building energy codes and regulations, energy calculation methodologies are becoming the major metric of energy performance of residential and non-residential buildings in various countries. The more clearly the metric can reflect actual energy performance of buildings, the more rapidly average energy efficiency of the building stock will be improved. Consequently, the emission rate of GHG from the building stock will be successfully reduced. If the metric failed in discriminating clearly enough buildings with better and worse energy efficiency, social resources invested in the operation of the building energy codes and regulations would not be efficiently utilized. This is the reason why policy makers and engineers concerned have been trying to improve reliability of the metrics for the building energy codes and regulations, as well as the social systems to operate them. This report does not deal with the social system, which is being dealt with by another working group in EBC TCP, which is entitled "Building Energy Codes"[22].

Among targets of building energy calculation, this report has focused upon the energy use of HVAC systems in non-residential buildings, which is predominant over other energy uses and seemed to be the most difficult target. The difficulty is partly because variety of non-residential buildings and of their HVAC systems.

It seems that each national calculation methodology for HVAC systems in non-residential buildings, which was reviewed in this report, has taken very long time to be developed with the engagement of each national building industry. Even though some common regional or international standards for thermal need calculation (e.g., ISO 13790) and equipment product standards (e.g. EN 14875, AHRI 550/590) are referred to, any coordination among national calculation methodologies does not exist. Unfortunately, that is the first major conclusion from the observation through this report. However, it is not necessary to recognize this situation pessimistically, and it seems that this situation reflects the fact that national practices in building and HVAC industries do not necessarily follow common standards for design and construction. At present, the most important subject is that each country will continue efforts to improve reliability of its energy calculation methodology, and that the countries will exchange knowledge and experience for the methodologies. This report seems to be the first trial to review the logics of national energy calculation methodologies for HVAC systems.

As a way to exchange and share internationally such knowledge and experience, there is an activity to develop international standards for building energy calculation as described in Section 6.1. This activity in CEN and ISO and its outputs should be followed up especially by Annexes and Working Groups in IEA EBC TCP. In addition, it is strongly recommended to contribute with their R&D outputs to the standardization activity.

The second and third major conclusions are a little bit detailed as follows. The energy use by HVAC systems is influenced by the factors including thermal needs (demands), heat losses in the process of heat conveyance/emission to the air-conditioned space, power for air/water conveyance, and heat/cold generation. Among these factors, in every national and international energy calculation methodology, there have been enormous endeavors on how to quantify energy uses for the power for air/water conveyance and

[22] Working Group on Building Energy Codes, https://iea-ebc.org/working-group/building-energy-codes

the heat/cold generation in HVAC systems. These energy uses predominant over other energy uses for HVAC systems, as exemplified in Figure 19. In spite of these endeavors, it seems that there are still much room for improving reliability and effectiveness of the methodologies for energy calculation, and it is required to further exchange information on the logic of relevant methods for energy calculation among countries and international standardization teams.

More specifically, as for the power for air/water conveyance in HVAC systems, in order to estimate electric power of motors for fan/pump, energy efficiencies of motors and variable frequency drive (i.e., inverter) under actual part load condition are necessary in addition to required power input by motors. Even if these parameters are not known when the energy calculation is done in early stages of the design process, reasonably assumed default values are required. In addition to optimized sizing of fan/pump systems, to conserve energy for air/water conveyance, control strategies for fan/pump to reduce air/water conveyance volume by responding to heat/cold needs are remarkably promising. However, it is revealed that definitions nor calculation logics for the control strategies have not yet been implemented in existing energy calculation methodologies.

As for heat/cold generation, even when sizing practices are carried out during the design, the partial load ratio (ratio of the current output to the capacity of the generators) can be quite low (e.g., 10% to 30%) in the majority of actual operation period. This is also the case of the fan/pump. Therefore, the energy efficiency of heat/cold generators under the low partial load ratio is critical in the energy calculation for the generators. However, as shown in Table 42 for cold generators, six national calculation methodologies apply different methods for estimating energy efficiencies under the low partial load ratio. Transparent approaches are needed to share information on actual behavior of heat/cold generators as a basis to further develop more reliable energy calculation methods. It is an intermediate area between the building industry and the HVAC equipment industry. The latter has had an objective of the product standards for efficiency comparison without information on installed buildings, but the former has tried to utilize the product standards for HVAC energy calculations with information on the buildings and climatic conditions of the building sites. The latter has searched for accuracy and reproducibility of test results and indices expressing annually average efficiencies, and the former is now searching for a method to estimate actual and absolute amount of energy use by heat/cold generators in designed buildings. At minimum, further R&D is needed in the building industry side in order to better understand the characteristics of various types of heat/cold generators, and to search for the reasonable ways to estimate energy efficiencies under the low partial load ratio.

The building energy calculation should never be what practitioners do only because it is mandatory. It should be reliable and useful enough as tools to estimate actual energy use in buildings.

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